Edmund G. Brown, Jr.
Governor

GEOGRAPHIC INFORMATION SYSTEM-ENABLED RENEWABLE ENERGY ANALYSIS CAPABILITY PROJECT FINAL REPORT

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Thomas Baginski
Lawrence Livermore National Laboratory

August 2011
CEC-500-2011-026

Prepared By:
Lawrence Livermore National Laboratory
Project Manager: Thomas Baginski
Author: Thomas Baginski
Livermore, California 94550
Commission Contract No. 500-06-017

Prepared For:
Public Interest Energy Research (PIER)
California Energy Commission

Mike Kane and Dianna Mircheva
Contract Managers

Linda Spiegel
Office Manager
Energy Generation Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

LLNL-TR-422987

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

GIS-Enabled Renewable Energy Analysis Capability Project Final Report is the final report for the GIS Enabled Renewable Energy Analysis Capability project (Contract Number 500-06-017) conducted by Lawrence Livermore National Laboratory. The information from this project contributes to PIER's Renewable Energy Technologies and Environmentally Preferred Advanced Generation Programs.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

Please cite this report as follows:

Baginski, T. 2011. *GIS-Enabled Renewable Energy Analysis Capability Project Final Report*. California Energy Commission, PIER Program. CEC-500-2011-026.

Table of Contents

Table of Figures

Note: All tables, figures, and photos in this report were produced by the authors, unless otherwise noted.

Abstract

This report summarizes the work completed by Lawrence Livermore National Laboratory and BEW Engineering under Contracts 500-06-017 and 500-06-017 Amendment #1. The report gives a project background, lists the project goals, and summarizes the project outcomes by task. The report highlights enhancements made to the project website, the California Renewable Resource Portal, available at https://calrenewableresource.llnl.gov/. The California Renewable Resource Portal consolidates and presents a large amount geographically-characterized wind, solar, geothermal, biomass, small hydropower and combined heat and power data and related information in an easy to use graphical format. By simplifying access to existing California renewable datasets, the website will help avoid costly duplication of effort, thereby benefitting California ratepayers and making it easier to implement California renewable energy and combined heat and power policy goals. The report attachment summarizes the Combined Heat and Power Transmission Impact Analysis completed by BEW Engineering.

Keywords: Combined heat and power, CHP, Renewables, wind, solar, geothermal, biomass, hydropower, GIS, geographic information system, California Renewable Resource Portal

Executive Summary

This project developed tools that incorporate Web and geographic information system technologies that provide forecasting and planning information to support analysis of renewable generation and conventionally fueled combined heat and power. Through this project, the research team developed an interactive Web-based capability that presents text, charts, and maps that help plan renewable and combined heat and power sites.

Lawrence Livermore National Laboratory's approach focused on four items: spatial data, portal management, interactive Web mapping, and geographic information system support for the Combined Heat and Power Transmission Impact Analysis. For spatial data, the project focused on regions with existing developed resource capacity, and on regions previously identified as having known, but underdeveloped resource potential. The project first evaluated the availability and coverage of existing data sources to avoid duplication of past efforts. For cases where existing data sources were unavailable or insufficient, the project developed new or updated geospatial data from source data. For portal management, the project enhancements were incorporated into the California Renewable Resource Portal available at https://calrenewableresource.llnl.gov/. The website follows modern Cascading Style Sheets-based styling and Web page authoring to create a user-friendly website layout and navigation. It also includes explanatory text and references where appropriate. For the interactive maps on the website, the project replaced the commercial map server previously used in a pilot project with an open-source map server and client. The project simplified the mapping interface to improve usability and performance. For the transmission impact analysis, the project needed to associate existing and potential combined heat and power sites with their connections point with the transmission grid. The project used available information to derive approximate locations for facilities. Based on the identified location, the project associated the facilities with their transmission grid connection point.

The project outcomes section reviews the project by task, and summarizes each task outcome and corresponding products as defined in the project scope of work. The project completed all project tasks and delivered all major products as specified in the scope of work. Where the deliverable varied from those originally listed in the scope of work, explanations and justifications are given. The report lists all the geospatial data used or developed for the project to support analysis of renewable resource and combined heat and power. The report also reviews the enhancement and additions made to the project website. Some highlights include: expanding the wind interactive mapping application to cover all five major wind resource areas, adding Web sections for solar, geothermal, biomass, small hydropower, and combined heat and power, and adding interactive map viewers for solar, geothermal, and combined heat and power.

The transmission impact analysis completed by BEW Engineering is documented in an attachment to this report. The analysis studied the transmission benefits of increasing the penetration of combined heat and power resources onto the California transmission grid. Depending on where the new combined heat and power potential is developed, the new capacity can improve or worsen transmission congestion problems on the grid. The analysis provides a way to optimize combined heat and power development in strategic areas that have technical potential and reduce transmission congestion. The analysis evaluates existing combined heat and power resources and potential combined heat and power resources in 2010. It provides a ranked list of regions where 2010 combined heat and power development will improve transmission reliability.

The project resulted in a publicly available website that presents geospatial data and other information for renewable and combined heat and power resources. The website will help the decision makers and developers evaluate critical resource and siting issues in the areas of wind, geothermal, biomass, solar, small hydropower, and combined heat and power. The website consolidates and presents a large amount of resource information, statistical study data, land use, and demographic planning data in a manner that is readily accessible to interested parties. During the project period, the website provided the ability to integrate, access, and disseminate spatial data for California analysis needs as it came available. The combined heat and power transmission impact analysis examined key resource development concerns for combined heat and power.

The project benefited California by:

- Evaluating and developing implementation paths for achieving renewable resource goals beyond 2010 including 33 percent renewables by 2020.
- Tracking development and repowering with a database of accurate, geospatial information useful for resource assessments and siting.
- Providing consistent and updated information on renewable resources for research and general public awareness.

1.0 Introduction

1.1. Background and Overview

The California Energy Commission funded this project under Contracts 500-06-017 and 500-06-017 Amendment #1. The first contract was signed in December 2006. Amendment #1 was signed in May 2007. Lawrence Livermore National Laboratory (LLNL) is the lead contractor. A portion of a task added in Amendment #1 is sub-contracted to BEW Engineering (BEW). Work started on the project in February 2007. The amended contract ended January 29, 2010.

This report summarizes work completed under the contract. The report lists the project goals. It then summarizes the project approach. Next, it reviews the project outcomes for each task in the scope of work. Finally, it concludes with recommendations and the benefits to California.

1.2. Project Goals

The purpose of this project is to develop tools that incorporate Web and geographic information system (GIS) technologies that provide forecasting and planning information benefitting an energy market with an increasing mix of renewable generation and conventionally fueled combined heat and power (CHP). Through this project, an interactive Web-based capability was developed that presents text, charts, and maps that aid analysis of renewable and CHP siting and planning. An earlier Energy Commission-supported project at LLNL developed a demonstration platform that consolidated wind data and provided the capability to display data for wind resource planning, siting, and repowering needs. The current project effort enhanced the demonstration platform into a Web-based renewable portal that contained resource information for all renewable resource areas (wind, solar, geothermal, biomass, and small hydropower) and for combined heat and power potential.

The project objectives stated in the contract include the following:

- Provide an interactive, analytical decision tool to evaluate critical resource and siting issues in the areas of wind, geothermal, biomass, solar, small hydropower, and combined heat and power.
- Consolidate resource information, statistical study data, land use, and demographic planning data to track and forecast development trends and to perform tradeoffs on development options.
- Provide and maintain the ability to integrate, access, and disseminate new spatial data for California analysis needs and work with the existing state GIS infrastructure to archive valuable resource information.
- Provide analysis on key resource development concerns including combined heat and power, wind repowering, solar photovoltaic (PV) development, concentrated solar power resource profiles, transmission corridors, environmental impact areas, distribution issues, and tracking of land use/right-of-way issues.

1.2.1. List of Project Tasks

The project has three main parts identified in the scope of work: preliminary activities, technical tasks, and reporting tasks. The technical tasks contain most of the project work that focused on the meeting the project goals. The individual subtasks are listed below.

- 1 Preliminary tasks
  - 1.1 Attend kick-off meeting
  - 1.2 Describe synergistic projects
  - 1.3 Identify required permits
- 2 Technical tasks
  - 2.1 Manage portal
  - 2.2 Collect and develop renewable energy geospatial data
  - 2.3 Enhanced renewable energy analysis capability
  - 2.4 Outreach and public workshop
  - 2.5 CHP analysis and Web interface
  - 2.6 Economic analysis and Web interface
- 3 Reporting tasks
  - 3.1 Progress reports
  - 3.2 Final report
  - 3.3 Final meeting

2.0 Project Approach

2.1. Spatial Data

One of the major project goals was to gather or generate geospatial data layers appropriate to support renewable and CHP resource analysis. The project used the following approach to meet this goal. Data layer development efforts focused on regions surrounding existing and potential resource areas within California. The project first evaluated the availability and coverage of existing data sources to avoid duplication of past effort. In many cases existing data sets met the project needs. For cases where existing data sources were not available or insufficient, the project developed new or updated geospatial data from source data. For example, the project created a new parcel based wind project area data set for the Altamont, Solano, and San Gorgonio wind resource areas. The project team used published environmental impact reports and other planning documents available from state and county sources to identify parcels with existing and planned wind projects. The team then digitized the identified parcels and attached appropriate attribute data. For all developed or updated data sets, the project team produced standardized metadata that documented the data, source, attributes, and other useful information. All original and updated geospatial data sets were delivered to the Energy Commission contract managers on a data disk. The project did not make the data available to the public on a statewide clearing-house as intended at the start of the project. The project team deferred to the Energy Commission contract managers on making the data available if they decide it is appropriate and there are no security constraints.

The specific data sets gathered and developed are documented below in the Project Outcomes section.

2.2. Portal Management

The project was tasked with enhancing the usability, maintainability, and performance needed to serve the renewable data and analysis capability of a Web-based portal. The project enhancements were incorporated into the California Renewable Resource Portal available at https://calrenewableresource.llnl.gov/. The website follows modern CSS-based styling and Web page authoring to create a user-friendly website layout and navigation. It also includes explanatory text and references where appropriate. To minimize system administration expenses, the project team moved the website from its own stand-alone Web server to an institutionally supported common Web server at LLNL. The institutionally supported Web server also provides performance improvements and fail-over support that improve reliability.

2.3. Interactive Web-Based Mapping

The project website includes several interactive Web mapping pages. The project replaced the commercial map server used in a pilot project with an open-source map server and client. The project simplified the mapping interface to improve usability and performance. The project also replaced internally generated base layers with base layers provided by Google Maps.

The Web-mapping tool developed at LLNL for the Altamont wind resource area through the earlier pilot project was developed with proprietary commercial software that need to run on its own mapping server. The map server software required an initial purchase fee and an annual maintenance fee for updates and support. The client interface and the server product were closely coupled and could not be changed independently. This pilot project implementation was appropriate for the technology that was available when it was developed, but newer Web mapping technology is now available without some of the previous disadvantages.

The project implemented the Web mapping improvements using open source Web mapping products. The Web client uses the OpenLayers framework (http://www.openlayers.org). The interface implemented is similar to common Web mapping service such as Google Maps. The Web client can also support several data formats from multiple sources using open Web mapping standards. The Web mapping server was developed using MapServer (http://mapserver.org/) and TileCache (http://tilecache.org/). Both are simple to use, free, and support open Web mapping standards. The final Web mapping tools were deployed using pre-generated map tiles so that no map server is needed at run time. This improves performance and simplifies server maintenance.

2.4. GIS Support for the CHP Transmission Impact Analysis

For Task 2.5 the project needed to associate existing and potential CHP sites with their connection points with the transmission grid. The location process is discussed first, and then the transmission grid association is discussed second.

The exact location of the existing and potential CHP sites was not directly available in the source data. The project used available information to derive approximate locations for facilities. The existing CHP site tabular data contained county and city information. The project located the facility at the centroid of the reported city. The CHP potential sites for large industrial facilities contained ZIP-code information. The project team made some updates to the ZIP-code data to remove some outdated values and replace them with current values. The facility location was then assigned based on the centroid of the ZIP-code. This location process was sufficient for the analysis and avoided the lengthy task of looking up the exact location of the hundreds of facilities in the source data.

Based on the identified location, the project associated the facilities with their transmission grid connection point. Facilities can connect to the transmission network at node called a bus. Buses are generally located at substations. More than one bus can be collocated at the same substation. LLNL staff matched the point locations of facilities with their closest bus point location using GIS. The team then confirmed that the reported electric utility of the facility matched the electric utility of the closest bus. For cases of mismatch, the closest bus from the same electric utility was found. Last, the bus associations for a few large facilities were manually checked based on the name, load, and generation fields in the bus data set. A small number of these large facilities were manually reassigned to more appropriate collocated or nearby busses.

3.0 Project Outcomes

The project tasks are listed above in Section 1.2.1. This section reviews the outcome and deliverables for each task. The project task number is listed in each heading since it differs from this documents section numbering.

3.1. Preliminary Tasks, Task 1

All three preliminary task have been completed. The initial kickoff meeting for 1.1 was held February 1, 2007. The kickoff meeting for the CHP task was held March 20, 2008. Letters describing the synergistic projects for 1.2 were submitted with the February 2007 progress report. A letter for 1.3 stating no permits were required was submitted at the February 2007 kickoff meeting and included with the February 2007 progress report.

3.2. Manage Portal, Task 2.1

The goal of this task is to enhance the usability, maintainability, and performance needed to serve the renewable data and analysis capability. It was an ongoing task that scheduled from project start to November 2009. All management activities for this task were completed by January 2010.

In 2007 the project team investigated a Web usage reporting system, performed system administration, and created an internal development server instance.

In 2008 the project website was migrated to the institutional Web server as discussed in section 2.2. During this time the research team also removed the pilot project Web map interface for the Altamont Pass.

In 2009, the project released the remaining task deliverables. The usage and user feedback repository is accessible by Energy Commission contract managers and project staff. This section of the website is password-restricted. The user guide is available on the website and is implemented as an annotated site map.

3.2.1. Task Deliverables Summary

The task deliverables and completion date or statuses are:

- Web-enabled Renewable Portal. This was released starting in December 2008 and is final as of January 2010.
- Usage and User Feedback Repository. This was delivered in August 2009.
- User Guide Report. Implemented as an annotated site map available on the website. It is final as of January 2010.

3.3. Develop Renewable Energy Geospatial Data, Task 2.2

LLNL staff compiled and generated geospatial data layers appropriate to support renewable resource analysis and address renewable development challenges. This section describes the data used during the project.

For data sets that LLNL generated, updated, or significantly modified, a copy of the new data was delivered to the Energy Commission contract managers. For data sets that LLNL did not originate, a description of the data and a reference to the definitive source are included. In some cases, due to copyright or security restrictions, LLNL cannot redistribute data used for this project. Descriptions of these restricted data are included in this list.

3.3.1. Geospatial Data Layers for Renewable Energy

National Solar Radiation Database 1961-1990

This data set contains solar radiation information for 10 monitoring station locations within California for 1961-1990. The data contain hourly time series when available. Some 40 km gridded data are available that were interpolated from the point locations. LLNL did not directly use this data. However, it does provide a historical time series of data if needed. The database can be accessed at http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/

National Solar Radiation Database 1991-2005 Update

This data set contains solar radiation information for 105 locations within California. It contains complete hourly data from 1991-2005 for all locations using interpolation when necessary. The update also has 10 km gridded data available for 1998-2005 which are the output of a model based on satellite data. The gridded data contain hourly solar radiation estimates for the entire eight-year time period. Approximately 4200 data points fall within California. The original data can be accessed at http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/. LLNL extracted subsets of these data for California that were used extensively in the solar section of the project website.

California Wind Energy Resource Maps

This data set was produced by AWS Truewind for the California Energy Commission (AWS Truewind 2006). It was originally published in 2002 and updated for some resource areas in 2006. The data set contains the a 200 m grid data with: 1) wind speed and wind power at 30 m, 50 m, 70 m, and 100 m; 2) Weibull distribution parameters C and k at 50 m. The data set also contains a 2 km grid data with wind rose frequencies, mean speeds, and percentage of energy. LLNL used these data extensively in the wind section of the project website.

Turbine and Turbine Footprints for Major Wind Resource Areas

These data were originally produced at LLNL in 2003 and 2004 as part of the pilot project. The footprint data are available for the Altamont, Pacheco, San Gorgonio, Solano, and Tehachapi wind resource areas. The individual turbine location data and footprint data were not updated for this project. These data are shown in the Wind section of the project website.

LLNL created an updated wind project area data set using current aerial photography, parcel outlines, and available planning documents to incorporate any newly developed areas for the Altamont, San Gorgonio, and Solano WRAs. LLNL also included planned wind energy development projects into this data set based on sites reported in available environmental impact report (EIR) data. EIR data was listed as a separate item in the "List of Existing and New Data Layers" deliverable. It was incorporated into this data set and not listed separately.

The data were delivered to the Energy Commission contract managers as shapefiles named: wind_ca_footprint.shp, wind_ca_turbines.shp, and wind_ca_project_area.shp.

California Known Geothermal Resource Areas

These data display California known geothermal resources areas and their current and potential generation capacity. The data set was received from the California Spatial Information Library. LLNL then updated the spatial and attribute data to reflect the figures reported in the Strategic Value Assessment project (Sison-Lebrilla and Tiangco 2005) and the Intermittency Analysis Project (Davis et al. 2007). This data set is used in the geothermal section of the project website. LLNL did not use the California geothermal well locations data set listed in the original data list.

The data were delivered to the Energy Commission contract managers as a shapefile named: geo_resource_areas.shp.

National Water Information System

This data was developed by the U.S. Geological Survey and reports real time stream flow information for more than 400 sites within California. LLNL used the 72 Hydro-Climate Data Network sites within California on the stream flow data sites page of the project website. The original data are available from the U.S. Geological Survey water data website at http://waterdata.usgs.gov/nwis/.

Existing Biomass by County

This tabular data set contains the existing and planned biomass capacity by county for 2005. It is based on data in *An Assessment of Biomass Resources in California, 2007* by the California Biomass Collaborative (Williams 2008). These data are used in the biomass section of the project website.

The data were delivered to the Energy Commission contract managers as a dBase table named biomassExistingByCounty2005.dbf

Biomass Technical Potential by County

This tabular data set contains the technical potential for biomass by county for 2007. It is based on data in *An Assessment of Biomass Resources in California, 2007* by the California Biomass Collaborative (Williams 2008). These data are used in the biomass section of the project website.

The data were delivered to the Energy Commission contract managers as a dBase table named biomassTechPotentialByCounty2007.dbf

Land Area in Biomass-Related Cover Types

These two tabular data sets contain the land area in forest and agricultural cover types summed by county. The agricultural data based on data in An Assessment of Biomass Resources in California, 2007 by the California Biomass Collaborative (Williams 2008). The Forest data were calculated by LLNL based on FRAP land cover data (FRAP 2002). These data are used in the biomass section of the project website.

The data were delivered to the Energy Commission contract managers as dBase tables named biomassForestAreaByCounty.dbf, and biomassAgricultureAreaByCounty.dbf

Land Use Data

The project team gathered several statewide land use data sets that include: multi-source land cover, public and conservation lands, easement areas, state and federal lands. These data were all downloaded from the California Spatial Information Library at http://atlas.ca.gov/download.html?sl=casil

General Plan Data

All county general plans and many city general plans are integrated and standardized into thirteen consistent land use classifications. This data set was downloaded from the California Spatial Information Library at http://atlas.ca.gov/download.html?sl=casil.

Farmlands Data

The California Department of Conservation Farmland Mapping and Monitoring Program (FMMP) data identifies agricultural land resources by county. LLNL used the 2006 version of the data. It can be accessed on the FMMP website at: http://www.conservation.ca.gov/dlrp/FMMP/Pages/Index.aspx.

Protected Areas

The California Protected Areas Database provides an inventory of all the protected open space lands in the State. This data set was downloaded from the California Spatial Information Library. The data are documented at: http://www.calands.org/

The airspace, Indian lands, and climatic data sets listed on the original data list were not gathered or used for this project.

3.3.2. Task Deliverables Summary

The task deliverables and delivery status are:

- List of existing and new data layers. This was completed in November 2007.
- Data sets and metadata. This was completed in September 2009.

3.4. Enhanced Renewable Energy Analysis Capability, Task 2.3

The goal of this task is to develop a Web based analysis capability focusing on each of the renewable resource areas including wind, solar, geothermal, biomass, and small hydropower. The task includes several subtask and deliverables which are described below. The main website of the project website is https://calrenewableresource.llnl.gov/. All enhancements completed for this project can be access via the website. The front page of the website is shown in Figure 1.

Figure 1. Project website front page

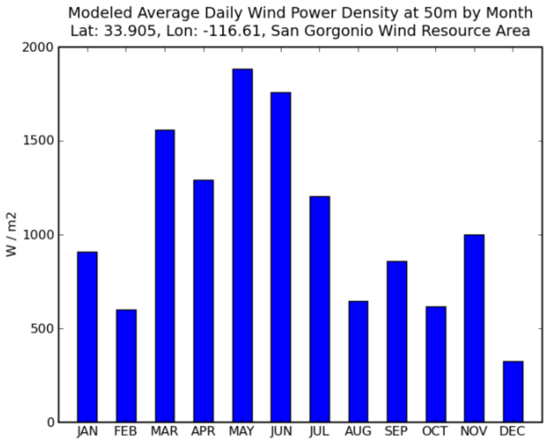
Source: Lawrence Livermore National Laboratory

3.4.1. Wind Website Enhancements

The wind section enhancements are available on the website at https://calrenewableresource.llnl.gov/wind/. The website now includes pages for the five major wind resource areas in California: Altamont, Tehachapi, San Gorgonio, Solano, and Pacheco Pass. The website also includes an interactive map viewer for these five wind resource areas. The map viewers incorporate the latest AWS Truewind data including: annual wind speed at 30m, 50m, 70m, and 100m; and annual wind power at 50m (AWS Truewind 2006). Where available the map viewer includes existing and proposed wind development parcels. The wind section also contains links to the Electronic Wind Performance Report Summary website as listed in the scope of work.

For four of the wind resource areas, LLNL developed wind profile graphs based on AWS Truewind modeled wind data (AWS Truewind 2006). The graphs show average daily wind power by month, average daily wind speed by month, hourly variation of average wind speed by season, and average wind speed by height. These were not included in the original task list. Two example graphs are shown in Figure 2. Both are for the same location in San Gorgonio.

The left graph show modeled average daily wind power at 50m by month. The right shows the hourly variation of average wind speed at 50m by season.



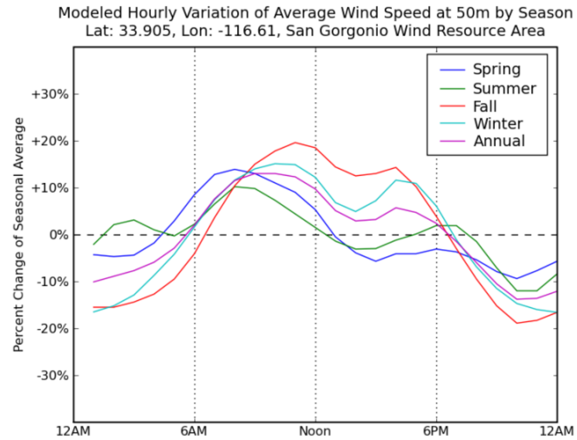


Figure 2. Example wind graphs

Source: Lawrence Livermore National Laboratory

3.4.2. Solar Website Enhancements

The solar section enhancements are available on the website at https://calrenewableresource.llnl.gov/solar/. The solar section includes maps and tables of solar resource potential by county, solar profiles by county and an animation of seasonal variation in solar radiation. The solar section make extensive use of the current National Solar Radiation Database Update 1991-2005 (NSRDB) as documented in Section 3.3.1. The solar section has a statewide interactive map viewer that shows annual and seasonal solar radiation using a 10km grid. The viewer also displays the location of all NSRDB monitoring station within California and provides links to a detail page for the station. The detail page for a station has graphs of year to year radiation, diurnal profile by season, cumulative relative frequency by season, and daily average by month. The detail page also provides direct links to the raw NSRDB data for the station. For counties without an NSRDB station, the authors create summary points at the county seat and generated similar summary data and charts as is shown for the NSRDB stations. The map viewer can link to the PVWATTS solar resource calculator application for a given location. All the listed solar enhancements from the scope of work are met by this application and the accompanying Web pages.

Examples of the solar map viewer and charts are shown below. Figure 3 shows an NSRDB station location near Livermore, CA. Figure 4 shows the corresponding diurnal profile chart that is included on the station detail page.

Figure 3. Example of solar map viewer

Source: Lawrence Livermore National Laboratory

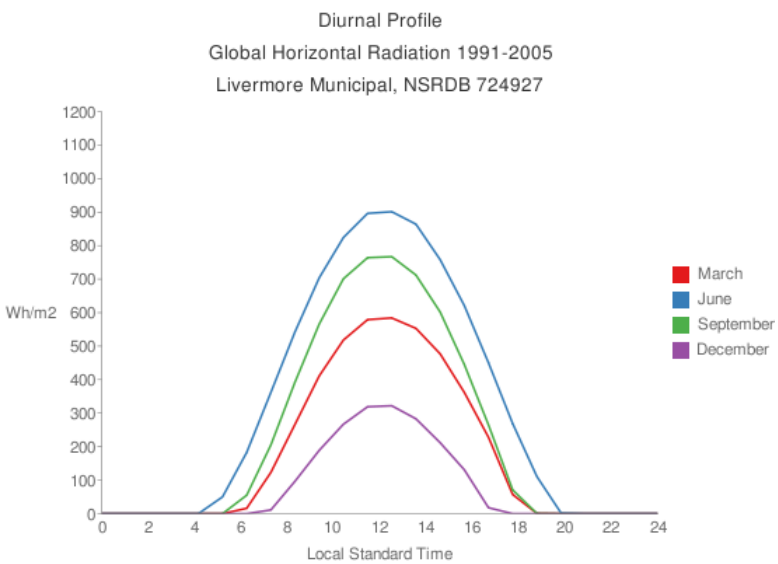


Figure 4. Example solar diurnal profile chart

Source: Lawrence Livermore National Laboratory

3.4.3. Geothermal Website Enhancements

The geothermal section enhancements are available on the website at https://calrenewableresource.llnl.gov/geothermal/. This section contains a table of the existing and predicted capacity at known geothermal resource areas. The website section summarizes geothermal capacity by county using maps and tables. An interactive geothermal map viewer displays the footprints of known geothermal resource areas and allows the user to query existing and potential capacity for these areas. The website does not list facility specific data or give the exact location of any existing individual geothermal facilities. All data are aggregated to the level of known geothermal resource areas. All the listed geothermal enhancements from the scope of work are met by the geothermal section of the website.

3.4.4. Biomass Website Enhancements

The biomass section enhancements are available at https://calrenewableresource.llnl.gov/biomass/. This section has static maps and tables of biomass potential by county. It also has maps and tables of the total area in potential biomass related land use categories summarized by county. It also includes links to the Energy Commission funded California Biomass Collaborative website. The section meets all the listed biomass enhancements from the scope of work.

3.4.5. Hydropower and Water Resource Website Enhancements

The hydropower and water resource section enhancements are available at https://calrenewableresource.llnl.gov/hydro/. The section summarizes hydropower by county using maps and tables. It provides a visualization of the variation in runoff during drought years and wet years. It shows the location and provides links to real-time flow data available through the USGS. The section meets all the listed hydropower enhancements from the scope of work except for the listing of hydro resource predictions from environmental models relevant to RPS. This enhancement was not included because other enhancement was given a higher priority.

3.4.6. Feasibility Study

The feasibility study of future website enhancements was completed in 2007. The project team completed this task in collaboration with the U.C. Berkeley Fire Center. A copy of the report was submitted to the Energy Commission contract manager in February 2008. The feasibility study addressed the potential tasks described in the contract, and it proposed cost estimates for each task.

3.4.7. Task Deliverables Summary

The task deliverables and completion date or statuses are:

- List of Enhanced Analysis Capabilities for the Renewable Portal. This was completed in February 2009.
- *Critical Project Review Report*. The Energy Commission contract managers and project staff held a critical project review in August 2008. The report was submitted at the review.
- Wind Section Enhancements. This was completed in August 2009.
- Solar Section. This was completed in August 2009
- Hydropower and water resource section. This was completed in November 2009.

- Geothermal Section. This was completed in August 2009.
- Biomass Section. This was completed in November 2009.
- Future website enhancements feasibility study. This was delivered in February 2008

3.5. Outreach and Public Workshop, Task 2.4

The goal of this task is to promote the capabilities of the project and website to interested stakeholders. The task specifies that the project shall staff present appropriate information at two conferences related to GIS analysis and/or renewable energy. LLNL staff presented a talk titled "Developing a Web-GIS Tool for Renewable Resource Analysis in California" at the Association of American Geographers Annual Meeting in April 2007. LLNL staff also presented a talk titled "Web Tools for Renewable Energy Analysis" at the Consortium on Climate Energy and Environment meeting in August 2007. Copies of both presentation slides were delivered to the Energy Commission contract manager. The scope of work also specified presenting on the project to interested stakeholders at a public workshop hosted by the Energy Commission. LLNL and BEW Engineering presented a summary of CHP work to date in December 2008 at the Commission hosted "Workshop on Geographical Information System Enabled Capability for Combined Heat and Power." Copies of the presentation material were delivered to the Commission contract mangers after the workshop.

3.5.1. Task Deliverables Summary

The task deliverables and completion date or statuses are:

- Copies of conference presentation materials. This was completed in April and August of 2007.
- Copies of workshop presentation materials. This was completed in December of 2008.

3.6. CHP Analysis and Web Interface, Task 2.5

The goal of this task is to compile or generate geospatial data layers appropriate to support analysis and siting of CHP and address development challenges. An additional goal is to assess the impact on electrical transmission grid congestion of adding potential CHP resources. This task was added through Amendment #1. The transmission impact analysis was subcontracted to BEW Engineering (BEW).

3.6.1. Geospatial Data Layers for CHP Analysis

LLNL compiled and generated geospatial data layers appropriate to support CHP resource analysis and to conduct the CHP transmission impacts analysis. The data layers are based on a list of existing and new data layers submitted to the Energy Commission contract manager in June 2009. This section describes the data used during the project.

For data sets that LLNL generated, updated, or significantly modified a copy of the new data was delivered to the Energy Commission contract managers. For data sets that LLNL did not originate, a description of the data and a reference to the definitive source is included. In some cases, due to copyright or security restrictions, LLNL cannot redistribute data used for this project. Descriptions of these restricted data are included in this list.

Existing CHP Sites in California

The authors used the ICF International (ICFI) "Combined Heat and Power Installation Database" as the basis for mapping existing CHP sites in California (Hampson 2009). There are 944 records in the current version of the California database. The database does not have the address or exact location of the sites. The research team used the city and county fields to approximate the site locations.

The data were delivered to the Energy Commission contract managers as a shapefile named chp_2009_existing.shp.

CHP Potential Sites

The research team used the ICFI "Industrial Sector Combined Heat and Power and Export Market Potential" data set as the basis for mapping potential CHP sites in California (Darrow et al. 2009). This database is documented in the May 2009 report cited above. ICFI provided LLNL with its draft results for the report. The research team used the draft results in its analysis because they were what were available when the authors needed the data. There are minor differences to the final report values. There are 947 sites in our copy of the data set. As with the existing site database, the address or exact location of the site is not reported. The authors used the ZIP code, city, and county fields to approximate the site locations.

The data were delivered to the Energy Commission contract managers as a shapefile named chp_mipd_final.shp.

California Electricity Transmission Bus Locations

The research team used the California electricity transmission bus location data set from the Strategic Value Analysis Project (Davis Power Consultants et al. 2005) and the Intermittency Analysis Project (Davis et al. 2007). The research team updated this data set with load, generation, and name data from the PowerWorld software package that BEW is using for the transmission impact analysis. Due to data use constraints, the authors cannot redistribute this. The authors used the data for internal analysis.

California Electricity Transmission Network and Flow

BEW maintains a model of the California electrical transmission system using proprietary data and the PowerWorld software package. BEW used data developed for previous projects including the Intermittency Analysis Project (Davis et al. 2007) and the Northern California Regional Integration of Renewables Project to model current and future electric demand, generation, and transmission flows. As stated in the scope of work, the network and transmission data is proprietary and will stay with BEW.

Natural Gas Service Areas

LLNL constructed a natural gas service area data layer using the Energy Commission provided natural gas service areas data set.

The data were delivered to the Energy Commission contract managers as a shapefile named natural_gas_service_area.shp.

Natural Gas Pipelines

The research team used the Energy Commission provided natural gas pipeline data set. LLNL did not make any modifications. The Commission already has a copy of this data set

The land use data sets are documented above in Section 3.3.13.3.

3.6.2. CHP Transmission Impact Analysis

The CHP transmission impact analysis was completed by BEW. The work is documented in the attached report. As discussed in Section 2.4, LLNL provided spatial data input and mapping support for this analysis.

3.6.3. CHP Web Interface

The CHP Web interface is available on the project websites at https://calrenewableresource.llnl.gov/chp/. The features developed for the Web interface are based on a list of enhancements submitted to the Energy Commission contract manager in August 2009. Existing and potential capacity are summarized by county and city using tables and maps. An example map from the website of existing CHP resources is shown in Figure 5. The results of the transmission impact analysis report are summarized into a series of Web pages. The pages use tables, charts, and maps from the report to display the results of the analysis. The website also includes an interactive Web map viewer for CHP resources. The map view displays map layers of existing capacity by county, existing capacity by city, onsite CHP potential, export CHP potential, and the summer 2020 case from the Transmission Impact Analysis. An example from the CHP map viewer is shown in Figure 6.

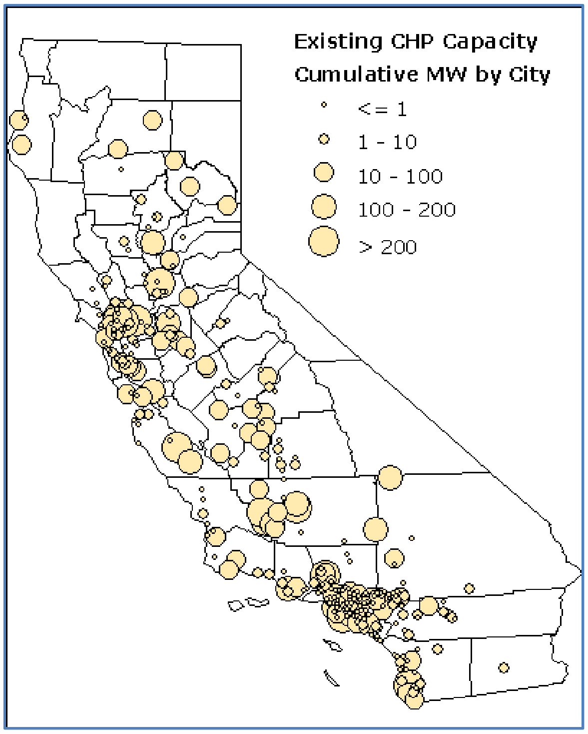


Figure 5. Example map, existing CHP capacity by city
Source: Lawrence Livermore National Laboratory

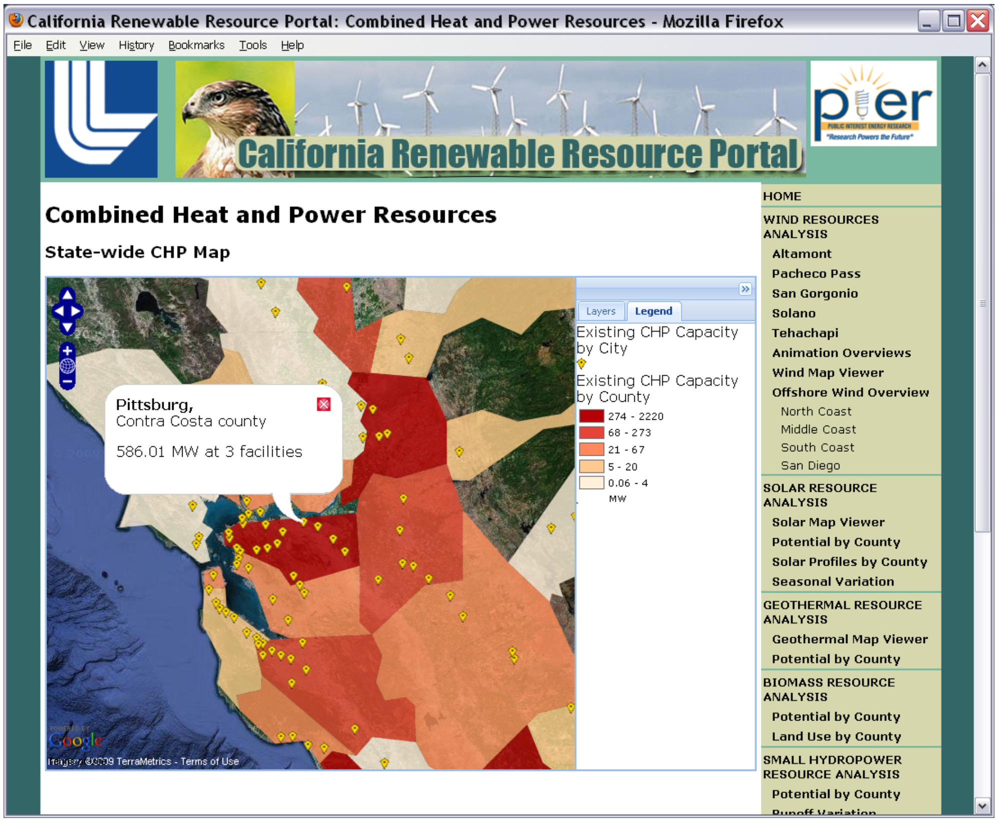


Figure 6. Example of the CHP map viewer

Source: Lawrence Livermore National Laboratory

3.6.4. Task Deliverables Summary

The task deliverables and completion date or statuses are:

- List of existing and new data layers. This was completed in June 2009.
- Data sets and metadata. This was completed in November 2009.
- CHP and transmission analysis report. This was completed by BEW in December 2009.
- List of capabilities for the Web interface. This was completed in August 2009.
- Web interface for CHP resource analysis. This was completed in December 2009.
- List of CHP development sites identified in analysis. This was completed in December 2009 and is included in the transmission impact analysis report. Counties were used for the ranking list instead of highlighting individual facilities.

3.7. Economic Analysis and Web Interface, Task 2.6

The goal of this task is to compile and generate geospatial data layers appropriate to support economic analyses for renewables and conventional fueled DG and CHP. A second goal is to present economic data layers on the website in appropriate formats.

3.7.1. Geospatial Data Layers for Economic Analysis

LLNL compiled and generated geospatial data layers based on a list of existing and new data layers submitted to the Energy Commission contract manager in July 2009. This section describes the data used during the project.

Commercial and Industrial Electricity Rates

LLNL transposed the electric rates maintained on the Energy Commission Energy Almanac website of utility-wide average electricity rate in nominal cents per kWh (California Energy Commission 2009). LLNL completed this for residential, commercial, and industrial user classes. The data cover 1982 – 2008. The data are in tabular form. LLNL added a NAME_LINK field that matched the NAME field in the Energy Commission provided Electric Service Area spatial data. The two data can be linked together using this field to allow visualization and spatial analysis of average utility rates. The price data are in nominal cents per kWh. GSP deflator figures are retained to allow conversion to constant 2007 prices.

The data were delivered to the Energy Commission contract managers as dBase tables named econ_elec_rate_commerical.dbf, econ_elec_rate_industrial.dbf, econ_elec_rate_residential.dbf, and econ_gsp_deflator.dbf.

Natural Gas Rates

LLNL extracted 1998 -2008 average natural gas rates for California from data maintained by the U.S. Energy Information Agency (EIA 2009). The data contain city gate, residential, commercial, industrial, and electric generation rates in nominal dollars per thousand cubic feet. Historical data for some of these rates is available through the EIA as far back as 1967. The source data are available at: http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_SCA_a.htm.

The data were delivered to the Energy Commission contract managers as a dBase table named econ_nat_gas_rate.dbf.

Locational Marginal Pricing (LMP) data

LLNL requested LMP data from the California Independent System Operator (California ISO). After several iterations, the California ISO) decided that it could not release the data to this project or the Energy Commission due to security and proprietary access restrictions for the data.

The Transmission congestion areas, demand growth, and land use data are described in Section 3.3.1. LLNL did not gather electric standby rate or incentive program data.

3.7.2. Website Enhancements for Economic Data

The project website presents economic data as part of the CHP section. The website shows charts of energy prices over time. Electricity prices are shown by utility for residential, commercial, and industrial customers. Natural gas prices are shown statewide for residential, commercial, industrial, and electric generation customers.

3.7.3. Task Deliverables Summary

The task deliverables and completion date or statuses are:

- List of existing and new data layers. This was completed in July 2009.
- Data sets and metadata. This was completed in January 2010.

3.8. Reporting, Task 3

LLNL submitted periodic progress reports to the Energy Commission contract manager. These reports were submitted monthly during periods of high project activity and less often during periods of low project activity.

This report is the project final report specified in the scope of work.

LLNL staff will meet with the Energy Commission contract managers as needed to conclude the project and present this report.

4.0 Conclusions and Recommendations

The project resulted in a publicly available website that presents geospatial data and other information for renewable and CHP resources. The website will help the decision makers and developers evaluate critical resource and siting issues in the areas of wind, geothermal, biomass, solar, small hydropower, and combined heat and power. The website consolidates and presents a large amount of resource information, statistical study data, land use, and demographic planning data in a manner that is readily accessible to interested parties. During the project period, the website provided the ability to integrate, access, and disseminate spatial data for California analysis needs as it came available. The CHP transmission impact analysis provided analysis on key resource development concerns for combined heat and power.

The project team recommends maintaining and updating the project website as new data becomes available. The project website will continue to be available as funding permits. LLNL can make updates and enhancements in the future with appropriate funding.

The project benefited California by supporting the following goals:

- Evaluate and develop implementation paths for achieving renewable resource goals beyond 2010 including 33 percent renewables by 2020
- Track development and repowering with a database of accurate, geospatial information useful for resource assessments and siting.
- Provide consistent and updated information on renewable resources for research and general public awareness.

5.0 References

AWS Truewind, LLC. 2006. *California Wind Energy Resource Modeling and Measurement*, California Energy Commission, PIER Program. CEC-500-2006-062.

California Energy Commission. 2009. *California Electricity Statistics and Data*. Last updated 2009, accessed December 2009, <http://www.energyalmanac.ca.gov/electricity/index.html>

Darrow, K., Hedman, B. and Hampson, A.. 2009. *Industrial Sector Combined Heat and Power Export Market Potential*. California Energy Commission, PIER Program. CEC-500—2009-010.

Davis Power Consultants, PowerWorld Corporation, Anthony Engineering. 2005. *Strategic Value Analysis for Integrating Renewable Technologies in Meeting Target Renewable Penetration*. California Energy Commission, PIER Program, CEC-500-2005-106.

Davis, R., Quach, B., Anthony Engineering, Davis Power Consultants, PowerWorld Corporation. 2007. *Intermittency Analysis Project : APPENDIX A - Intermittency Impacts of Wind and Solar Resources on Transmission Reliability*, California Energy Commission, PIER Program, CEC-500-2007-081-APA.

EIA, 2009. *California Natural Gas Prices*, U. S. Energy Information Administration, release date December 29, 2009, accessed January 2010, <http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_SCA_a.htm>.

FRAP. 2002. *Multi-source Land Cover Data (v02_1) fveg02_1*, California Department of Forestry and Fire Protection, Sacramento California.

Hampson, A. 2009. *Combined Heat and Power Installation Database*. ICF International, last updated January 21 2009, accessed August 2009, <http://www.eea-inc.com/chpdata/index.html>.

Sison-Lebrilla, E. and Tiangco, V. 2005. *Geothermal Strategic Value Analysis – DRAFT STAFF PAPER*, California Energy Commission, PIER Program CEC-500-2005-105-SD.

Williams, R. 2008. *An Assessment of Biomass Resources in California, 2007*, California Biomass Collaborative, Davis, CA

Attachment I

Davis, R., Stewart, E., Quach, B., Anjum, N., Baginski, T. 2010. *Combined Heat and Power Transmission Impact Analysis*. LLNL-SR-422662.

LLNL-SR-422662

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Combined Heat and Power Transmission Impact Analysis

R. Davis, E. Stewart, B. Quach, N. Anjum, T. A. Baginski

January 21, 2010

Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Combined Heat and Power Transmission Impact Analysis

Report to Lawrence Livermore National Laboratory

Prepared by BEW Engineering

Ron Davis, Emma Stewart, Billy Quach, Neelofar Anjum

and

Thomas Baginski, Lawrence Livermore National Laboratory

January 2009

CONTENTS

FIGURES

TABLES

ABSTRACT

The State of California requires the investor owned utilities (IOU) to secure renewable resources to meet a Renewable Penetration Standard (RPS) of 33% energy target by 2020. This energy target represents 33% of the IOUs retail customer load. The resources to meet the renewable energy targets include wind, solar, biomass, geothermal and hydroelectric. In addition, the IOUs and the public power utilities must meet a residential PV penetration of 1 million new homes with solar by 2020 which is equivalent to 3,000 MW. The million new residential homes with PV is mandated under the California Solar initiative (CSI). The objectives of the RPS and CSI is to increase the generation from renewable resources, decrease California's dependence on natural gas and oil, and reduce green house gases.

The California Energy Commission (Energy Commission) has been in the forefront in retaining consultants to study high penetrations of renewable resources. The Energy Commission has been concerned about transmission availability and reliability as high penetrations of renewables grow. They have initiated the Strategic Value Analysis (SVA), the Intermittency Analysis Project (IAP) and other studies.

An important generating resource that has not been fully developed or analyzed are the distributed self generation and steam boiler resources. Many commercial and industrial companies require high steam loads to drive their production which are produced by older natural gas fired steam boilers. The companies may have older combined cycle generating plants that were sized to match the steam loads. The Energy Commission was interested on the potential for replacing these older steam boilers and cogeneration plants with more efficient combined cycle plants. The goal was to determine the transmission and distribution efficiency improvements, reduction in natural gas and oil consumption and if there are green house gas savings by displacing older steam boilers, old cogeneration plants, and reduce the use of older utility owned conventional generating plants.

The Energy Commission retained Lawrence Livermore National Laboratory (LLNL) and BEW Engineering (BEW) to conduct a study in year 2020 to determine the potential for green house gas reductions and natural gas reductions. The customer owned plants were divided into three areas: 0 to 5 MW, 5 to 20 MW and Greater than 20 MW. Transmission power flow analyses was completed to investigate the potential for savings and prioritize the counties for the Energy Commission, California Public Utility Commission and the utilities to pursue.

1 INTRODUCTION

BEW Engineering (BEW) was retained through Lawrence Livermore National Laboratory (LLNL) to conduct a study on the green house gas reduction potential and natural gas reductions if older steam boilers and cogeneration plants on the distribution system could be replaced with more efficient cogeneration plants. This study was called the Combined Heat and Power Study (CHP).

From publicly available information on steam boilers and old cogeneration plants, LLNL was able to find the location of these plants on a transmission map. LLNL determined the most likely substation that the CHP was connected. By knowing the substation location, LLNL could also provide the county and zip code that that CHP was located. LLNL further refined the CHP data into three classes: 0 to 5 MW, 5 to 20 MW, and Greater than 20 MW.

BEW used this information to conduct transmission power flow studies to determine which class of CHP resource potential was the most beneficial, the reduction in natural gas usage and reduction in green house gases. From the analysis, BEW selected those counties with the highest CHP potential and those counties that were the least potential.

This report summarizes the results of the LLNL and BEW analysis.

2 CONCLUSIONS

There are three Combined Heat and Power (CHP) Classifications: 0 to 5 MW, 5 to 20 MW and Greater than 20 MW. Table 1 shows the potential generating capacity for each CHP classification for each utility. The majority of the CHP potential (53%) is located in the PG&E service area with LADWP and SCE sharing second at 24% and 21%, respectively.

Table 1: Potential CHP Generating Capacity by Classification per Utility

Location	0 to 5 MW	5 to 20 MW	Greater than 20 MW	Total	Percent of Total
PG&E	197	410	3,504	4,111	53%
SCE	196	202	1,261	1,659	21%
SDG&E	17	14	0	31	0.4%
LADWP	38	6	1,792	1,836	24%
IID	0	0	114	114	1.6%
Total	448	632	6,671	7,751	100%

The three CHP classifications are divided into four scenarios: 0 to 5 MW, 5 to 20 MW, 0 to 20 MW and 0 to Greater than 20 MW for transmission power flow analysis. The power flow results divide the counties into three categories: CHP provides high transmission value; CHP results are indifferent to transmission impacts; and CHP is a detriment to transmission reliability. Table 2 lists the counties that provide the highest transmission beneficial value. Transmission beneficial value is measured using the Renewable Transmission Benefit Ratio (RTBR), described in Section 3. All of the counties are listed in at least two of the CHP categories, except for Alameda and San Joaquin that provide a benefit in the 0 to 5 MW scenarios only.

Table 2: Counties that have Negative CHP RTBR Values (Benefit)

RTBR 0-5	RTBR 5-20	RTBR 0-20	RTBR 0-20+
ALAMEDA	BUTTE	BUTTE	BUTTE
FRESNO	FRESNO	KERN	KERN
SACRAMENTO	KERN	KINGS	KINGS
SAN JOAQUIN	KINGS	PLACER	PLACER
SONOMA		SACRAMENTO	SACRAMENTO
TEHAMA		SONOMA	SONOMA

RTBR 0-5	RTBR 5-20	RTBR 0-20	RTBR 0-20+
YOLO		TEHAMA	TEHAMA
		YOLO	YOLO

Table 3 lists the counties with high positive CHP RTBR values. The CHP injection in these counties requires transmission upgrades to facilitate CHP development. The list of counties is consistent across all scenarios.

Table 3: Counties with High Positive CHP RTBR Values

RTBR 0-5	RTBR 5-20	RTBR 0-20	RTBR 0-20+
HUMBOLDT	ALAMEDA	CONTRA COSTA	CONTRA COSTA
	CONTRA COSTA	HUMBOLDT	HUMBOLDT
	HUMBOLDT	MENDOCINO	KERN
	MENDOCINO	VENTURA	MADERA
	SHASTA		SAN BERNARDINO
	VENTURA		TULARE
			VENTURA

Table 4 shows the fuel savings and emission reductions per CHP classification. The assumption is that all of the re-dispatched conventional gas units are the older less efficient units and have the worst emission records. There is some concern that the units in the 0 to 5 MW classification are not large enough to provide a reasonable heat rate curve and achieve the savings shown. The Greater than 20 MW classification displays high fuel and emission savings. The transmission upgrades and congestion in some counties may reduce the overall benefit of this classification.

Table 4: Fuel Savings and Emission Reductions by CHP Classification

CHP Size	MW of Units Dispatched	Fuel Saved (MMBTu/YR), 90% Capacity Factor	CO_2 reduction (TonCO2/YR), 90% Capacity Factor	NOx Reduction (lbNOx/YR), 90% capacity Factor
0 to 5 MW	371	15,596,843	912,415	311,937
5 to 20 MW	486	12,090,672	1,703,742	582,476
>20 MW	4,173	84,558,130	5,517,609	1,886,362
TOTAL	**5,030**	**112,245,645**	**8,133,766**	**2,780,775**

Although not directly a part of the CHP study, Table 5 compares the fuel savings and emission reductions between CHP resources and PV resources. Since a PV resource displaces 100% of conventional generation, the savings per MWh is substantially higher than a CHP resource but the energy produced by PV is at a 17% capacity factor compared to a 90% for CHP.

Table 5: Comparison of CHP and PV for Fuel Savings and Emission Reductions

	CHP	PV
MW	5,030	2,895
C.F.	90%	17%
Energy	39,656,520	4,311,234
Fuel Saved MMBTU/yr	112,245,645	31,864,643
CO2 Reduction TonCo2/yr	8,133,766	1,864,140
NOx Reduction lbNOx/yr	2,780,775	2,230,595
Fuel Saved MMBTU/MWh	2.83	7.39
CO2 Reduction TonCo2/MWh	0.21	0.43
NOx Reduction lbNOx/MWh	0.07	0.52

2.1 Summary of 2020 Results

The counties are ranked on the basis of the average RTBR results for Spring, Summer and Fall. The rankings are shown by utility and type of area (Urban or Rural). The results were split by Urban and Rural counties. In general urban counties have more CHP and are more congested therefore the benefits and detrimental effects are split, allowing the effect of the CHP in each type of area to be clearly defined. In each ranking table, the grey areas indicate the overall RTBR was positive, and therefore overall throughout the seasons the effect of the CHP is detrimental.

For the PG&E urban counties, the majority of the CHP categories with the lowest ranking are in the 0 to 5 MW category, as shown in Table 6. This is expected since the 0 to 5 MW have small CHP megawatt penetrations and are load reducing resources. It should be noted that the rankings vary by season. For example, Sacramento County in the 0 to 5 MW category has an overall ranking of 1 but the fall ranking is 14 out of 17 counties. In the top 10 rankings, the four categories in Fresno County are included along with three of the four categories in Sacramento County. Rounding out the bottom is Contra Costa County.

Table 6: Ranking of PG&E Urban Counties

PGE	URBAN COUNTIES					
COUNTY	**MW RANGE**	**No of MW**	**Ranking Summer**	**Ranking Spring**	**Ranking Fall**	**Overall Ranking**
SACRAMENTO	0 TO 5	12	1	5	14	**1**
FRESNO	0 TO 5	15	5	2	1	**2**
ALAMEDA	0 TO 5	15	3	1	6	**3**
SACRAMENTO	0 TO 20	18	2	4	15	**4**
FRESNO	5 TO 20	19	6	15	3	**5**
FRESNO	0 TO 20	34	7	14	2	**6**
FRESNO	0 TO 20+	93	8	16	4	**7**
SACRAMENTO	5 TO 20	6	4	7	16	**8**
SANTA CLARA	0 TO 5	15	10	8	11	**9**
SANTA CLARA	0 TO 20	32	11	12	5	**10**
SANTA CLARA	5 TO 20	17	9	11	9	**11**
ALAMEDA	0 TO 20	50	12	3	13	**12**
CONTRA COSTA	0 TO 20	13	14	6	10	**13**
CONTRA COSTA	0 TO 5	7	15	10	7	**14**
CONTRA COSTA	5 TO 20	6	16	9	8	**15**
ALAMEDA	5 TO 20	35	17	13	12	**16**
CONTRA COSTA	0 TO 20+	177	13	17	17	**17**

Table 7 shows the PG&E rural ranking. These ranking results are very different than the urban results. In the rural rankings, there is no consistent CHP category that produces consistent results across the three seasons. Madera is the only consistent county in the lowest ranked counties. The least beneficial counties are Humboldt and Mendocino in all seasons and categories.

Table 7: PG&E rural counties ranking

PGE	RURAL COUNTIES					
COUNTY	**MW RANGE**	**No of MW**	**Ranking Summer**	**Ranking Spring**	**Ranking Fall**	**Overall Ranking**
KERN	5 to 20	37	21	1	1	**1**
MADERA	0 to 5	6	4	3	4	**2**
SAN JOAQUIN	0 to 5	25	1	10	14	**3**
KINGS	5 to 20	7	11	4	5	**4**
SONOMA	0 to 5	5	2	12	24	**5**
MADERA	0 to 20	16	25	6	3	**6**
SAN JOAQUIN	0 to 20	38	3	13	20	**7**
MADERA	0 to +20	73	22	17	2	**8**
PLACER	5 to 20	11	9	2	25	**9**
SOLANO	0 to 5	7	5	11	9	**10**
SAN JOAQUIN	0 to +20	63	6	16	18	**11**
STANISLAUS	0 to 5	12	8	5	15	**12**
SAN JOAQUIN	5 to 20	13	7	9	22	**13**
MERCED	0 to 5	12	10	7	13	**14**
MERCED	5 to 20	42	18	19	6	**15**
MERCED	0 to 20	54	16	24	8	**16**
MERCED	0 to +20	301	19	26	7	**17**
STANISLAUS	0 to 20	44	13	8	21	**18**
STANISLAUS	5 to 20	32	14	15	23	**19**
SOLANO	0 to +20	123	12	23	16	**20**
LASSEN	5 to 20	11	15	21	11	**21**
STANISLAUS	0 to +20	103	17	14	17	**22**
SANTA CRUZ	5 to 20	16	20	20	10	**23**
MONTEREY	5 to 20	7	23	22	12	**24**
MONTEREY	0 to +20	63	31	25	19	**25**
MENDOCINO *	0 to +20	156	27	27	26	**26**
MADERA	5 to 20	9	24	18	28	**27**
MENDOCINO *	5 to 20	16	28	28	27	**28**
HUMBOLDT *	0 to 5	11	26	31	31	**29**
HUMBOLDT *	5 to 20	10	29	29	30	**30**
HUMBOLDT *	0 to 20	21	30	30	29	**31**

PGE	RURAL COUNTIES					
COUNTY	MW RANGE	No of MW	Ranking Summer	Ranking Spring	Ranking Fall	Overall Ranking
HUMBOLDT *	0 to +20	135	32	32	32	**32**

Table 8 lists the results for the three SCE urban counties. Los Angeles and Orange Counties have the lowest ranking.

Table 8: SCE Urban County Ranking

SCE	URBAN COUNTIES					
County	MW Range	No Of MW	Ranking Summer	Ranking Spring	Ranking Fall	Overall Ranking
LOS ANGELES	5 - 20	101	1	1	7	**1**
LOS ANGELES	0 - 20	227	2	2	2	**2**
LOS ANGELES	0 -5	126	3	6	1	**3**
ORANGE	0 -5	28	4	3	4	**4**
ORANGE	0 - 20	56	6	4	5	**5**
ORANGE	0 - 20+	56	7	5	8	**6**
ORANGE	5 - 20	28	8	7	9	**7**
LOS ANGELES	0 - 20+	1135	5	9	3	**8**
RIVERSIDE	0 -5	11	9	8	6	**9**

Table 9 shows the RTBR results for the SCE rural counties. The lowest ranked counties are in the 0 to 5 MW category and the 5 to 20 MW category. The highest ranked counties are in the 0 to 20 MW or Greater category.

Table 9: SCE Rural County Ranking

SCE	RURAL COUNTIES					
County	MW RANGE	No of MW	Ranking Summer	Ranking Spring	Ranking Fall	Overall Ranking
VENTURA	5 - 20	18	3	1	1	**1**
SAN BERNARDINO *	0 -5	10	1	4	6	**2**
SAN BERNARDINO *	5 - 20	37	2	5	7	**3**
VENTURA	0 -5	10	4	6	3	**4**
SAN	0 - 20	47	5	7	8	**5**

SCE	RURAL COUNTIES					
County	**MW RANGE**	**No of MW**	**Ranking Summer**	**Ranking Spring**	**Ranking Fall**	**Overall Ranking**
BERNARDINO *						
TULARE	0 - 20+	115	6	8	5	**6**
KERN	0 - 20+	163	7	9	9	**7**
SAN BERNARDINO *	0 - 20+	88	8	10	10	**8**
VENTURA	0 - 20+	52	9	3	4	**9**
VENTURA	0 - 20	28	10	2	2	**10**

Table 10 lists the RTBR results for SDG&E, IID and LADWP. In San Diego County, the 5 to 20 MW category is the most beneficial when RTBR's are averaged over all three seasons. The rankings are the same whether Summer, Spring or Fall is considered in the other utility areas. Los Angeles County in the LADWP utility is the least beneficial overall in the 0 to Greater than 20 MW category.

Table 10: Other counties (SDG&E, LADWP, IID) ranking

OTHER UTILITIES						
COUNTY	**MW Range**	**No of MW**	**Ranking Summer**	**Ranking Spring**	**Ranking Fall**	**Overall Ranking**
SAN DIEGO (SDG&E)	5 – 20	14	1	1	1	**1**
SAN DIEGO (SDG&E)	0 – 20	30	2	2	2	**2**
SAN DIEGO (SDG&E)	0 - 20+	30	3	3	3	**3**
SAN DIEGO (SDG&E)	0 -5	16	4	4	4	**4**
LOS ANGELES (LADWP)	0 -5	38	5	5	5	**5**
IMPERIAL (IID)	0 - 20+	106	6	6	6	**6**
LOS ANGELES (LADWP)	0 - 20+	1705	7	7	7	**7**

2.2 Utility and State Wide Summaries

Table 11 shows the RTBR results for each utility and state-wide (all utilities combined). As expected, the 0 to 5 MW and the 5 to 20 MW categories produced the lowest overall ranking for the utilities. This is expected since the CHP sizes are actually load reducing at the CHP site and thus lowers transmission and distribution line loadings.

Table 11: Utility and State-Wide RTBR Rankings

	Category	CHP MW	Summer Ranking	Spring Ranking	Fall Ranking	Overall Ranking
PGE	0 to 5 MW	197	1	7	19	1
PGE	0 to 20 MW	506	3	3	20	2
ALL CA	0 to 5 MW	452	2	21	3	3
SCE	0 to 5 MW	196	6	8	2	4
PGE	5 to 20 MW	309	4	1	23	5
SDGE	5 to 20 MW	14	5	18	11	6
ALL CA	0 to 20 MW	936	8	6	17	7
SDGE	0 to 20 MW	31	7	19	12	8
SDGE	0 to 5 MW	17	9	17	10	9
LADWP	0 to 5 MW	38	10	9	1	10
LADWP	0 to 20 MW	38	11	11	4	11
ALL CA	5 to 20 MW	484	14	5	18	12
SCE	0 to 20 MW	368	22	4	5	13
LADWP	5 to 20 MW	0	16	10	6	14
IID	0 to 5 MW	0	17	13	7	15
IID	5 to 20 MW	0	18	14	8	16
IID	0 to 20 MW	0	19	15	9	17
SDGE	ALL CHP MW	31	20	20	13	18
SCE	ALL CHP MW	2207	21	24	16	19
ALL CA	ALL CHP MW	4015	13	22	21	20
IID	ALL CHP MW	106	15	16	22	21
LADWP	ALL CHP MW	1705	23	12	15	22
SCE	5 to 20 MW	172	24	2	14	23
PGE	ALL CHP MW	1473	12	23	24	24

The scenarios that have the highest ranking are the 0 to Greater than 20 MW (shown as All CHP). The main reason for the ALL CHP to be ranked at the bottom of the rankings is the high cumulative penetration of CHP. The All CHP penetrations range from 1,700 MW to 4,000 MW with the majority of the generation in the Greater than 20 MW classification. Since these large CHP are exporting to the grid, there are transmission overloads that need to be resolved. For the All CA and All CHP scenario, if the 4,015 MW is reduced by 1,000 MW, then the RTBR reduces from a positive RTBR to zero (0).

Table 12 shows the fuel saved and the emission reductions per utility if all of the CHP resources are installed as shown in the previous tables. Even though the CHP resources are still burning natural gas, the fuel savings are derived from displacing steam boilers and older less efficient gas fueled power plants with more efficient and less polluting combined cycle plants. The CO2 and NOx reductions are based on the power plant operating on an annual capacity factor of 90%.

Table 12: Fuel Saved and Emission Reductions per Utility

Utility	MW of Units Dispatched	Fuel Saved (MMBTu/Yr), 90% Capacity Factor	CO2 reduction (TonCO2/YR), 90% Capacity Factor	Nox Reduction (lbNOx/YR), 90% Capacity Factor
PG&E	1,521	33,845,019	2,855,477	976,231
SCE	1,659	56,855,559	4,017,903	1,373,642
LADWP	1,705	14,882,078	870,602	297,642
IID & SDG&E	145	6,662,989	389,785	133,260
Total	5,030	112,245,645	8,133,766	2,780,775

The injection of 2,895 MW of PV resources reduces fuel consumption and emissions by displacing conventional generating resources.

Table 13 lists the savings from the installation of 2,895 MW of residential PV resources operating at an annual capacity of 15%.

Table 13: Fuel Savings and Emission Reductions from PV

MW of Units Installed	Fuel Saved (MMBTu/Yr)	CO2 reduction (TonCO2/Yr)	NOx Reduction (lbNOx/Yr)
2895	**31,864,643**	**1,864,140**	**2,230,595**

3 ANALYSIS METHODOLOGY

The methodology for evaluating the transmission benefits of CHP is based on the Aggregated Mega-Watt Contingency Overload (AMWCO) index, developed under the California Energy Commission's Public Interest Energy Program (PIER) program for evaluating renewable penetrations and reliability benefits. The methodology was first developed in the 2005 Locational Value Analysis of Renewable Technologies Study (SVA) and enhanced in PIER Intermittency Analysis Project (IAP). The SVA methodology was later changed to the Renewable Transmission Benefit Ratio (RTBR) analysis.

In the SVA and IAP, several analytical tools are developed to evaluate the transmission system performance under various scenarios, renewable mixes, and intermittent resource production levels. An analytical approach to transmission system expansion requires the simulation of the transmission system under a set of contingencies. Typically, transmission systems are built with redundancy to withstand severe contingencies without losing load or experiencing security violations such as transmission overloads. The effects of contingencies are tabulated to determine useful metrics to evaluate transmission grid reliability.

For each scenario, a set of N-1 contingencies produce a list of overloaded transmission elements. The study considers all contingent outages of single transmission lines, single transformers, and single generators (n-1), and measured contingency overloads only on non-radial transmission elements in California. The simulations incorporated linear approximations of post-contingent conditions to reduce simulation runtime. The linear approximations use flow sensitivities to estimate changes in real power flows and did not evaluate reactive power flows.

The percent overload of the element is weighted by the number of outage occurrences. For a particular line outage, or contingency there are overloaded elements. Each overload element percentage is subtracted by 100% and summed. This value is multiplied by the line rating (MVA) to achieve the AMWCO value for that line outage. All of the individual AWMCO values are summed to achieve a System AMWCO value. The delta AMWCO is the difference between the system AMWCO for the base case and each new renewable case. Delta AMWCO is therefore a transmission reliability index, with a unit of megawatts.

A negative delta AMWCO, a decrease in the AMWCO, indicates an improvement in transmission reliability. The larger the negative delta AMWCO, the more beneficial the transmission element is to the transmission system. For example, if 10 MW of CHP reduces the base AMWCO from 1,012 to 1,000, then the delta AMWCO is -12, and there is a benefit to the system. Comparing delta AMWCO's is difficult since the numbers vary considerably.

If the delta AMWCO is divided by the megawatt of CHP, then an index per MW injected can be determined. The Renewable Transmission Benefit Ratio (RTBR) is the change in System AMWCO per MW of CHP generation. Thus RTBR measures the impact of the CHP resource on system security. Negative RTBR indicates an improvement in system security.

$$RTBR = \frac{AMWCO_{renewable} - AMWCO_{base}}{MW_{renewable}}$$

In the above example, if the CHP megawatt is 10 MW, the AMWCO per MW is – 1.2. A RTBR of -1.2 means that 1 MW of new CHP generation on the system is likely to reduce 1.2 MW of the overall system overloads in the system.

More information on AMWCO can be found in the Energy Commission's report "Strategic Value Analysis for Integrating Renewable Technologies in Meeting Renewable Penetration Targets, June 2005, CEC-500-2005-106".

4 CASE DEVELOPMENT

The proposed CHP generation is divided into three categories based on generator size: 0 to 5 MW; 5 to 20 MW; and Greater than 20 MW. The total generating capacity for each category and the number of CHP and residential PV units are shown in Table 14. The average size of the CHP unit for each category is also shown. There are more individual 0 to 5 MW CHP generators than the other two CHP categories combined but the average size of each CHP is 2 MW. It is anticipated that the contribution to transmission and/or distribution reliability could be minimal from this category given the distribution across the entire state of California. There are a smaller number of CHP units in the 5-20 MW category but the average size of 10 MW could be economical to pursue. The Greater than 20 MW category has fewer generators but the average megawatt size of 163 MW may cause more overloads than benefits on the system.

There are 1,653 MW of residential PV modeled in the data set at 215 locations. The average size of residential PV is 8 MW indicates that the residential PV units were aggregated together.

Table 14: Total MW available for dispatch

Generation Size Category	PV	0-5 MW CHP	5-20 MW CHP	20+ MW CHP	Total CHP Available
MW	1,653	452	638	6,671	7,761
No of Units	215	228	62	41	331
Average Size of CHP Unit	8	2	10	163	23

The projected CHP generators are sorted by location; zip code, county and utility. All the generating units in each county are aggregated based on the three size categories listed above. The transmission interconnection point for each generating unit is based on the zip code. BEW provided LLNL with the locations of all of the substations in the California transmission data set. Using this data and the CHP addresses with zip codes, LLNL assigned the CHP generators to the closest transmission substation. Since there could be several substations and/or substation buses located near the CHP generator, BEW and LLNL worked together to select the most likely substation to assign the CHP generator. The initial assignments may have changed depending on the size of the CHP generator.

Once the substation assignments are completed, LLNL assigns the county in which the substation is located. BEW assigned the final substation injection to the proper utility. The locations are summarized in the maps located in Appendix I, detailing graphically for each utility the location, and number of units.

There is 2,850 MW of solar PV included in this analysis. The summer and spring base cases have 2,850 MW of solar PV that are derated to 58% of the maximum capacity, to represent the difference between the peak load period and peak solar generation. The coincidence factor is based on studies by the Energy Commission. The PV resources represent the California requirements for one million homes or 3,000 MW of residential PV by 2020. The PV resources are modeled in the base case so that each CHP scenario has the same PV resources.

The RTBR value of CHP resources on transmission reliability is first analyzed on a county-by county-basis. Even though the analysis is completed for each county, the power flow simulations are completed for the utility system where the CHP generator and county reside. Since transmission lines cross county boundaries, the power flow simulations need to model the entire electric utility system. After the county-by-county analysis is completed, the analysis evaluates the impacts of CHP generators on a utility-wide basis. The final analysis is completed for the entire state. Because the generator capacities in the 0 to 5 MW category are so small, only the counties that have a total cumulative capacity of 5 MW or greater are included in the power flow studies. The counties with a cumulative CHP generating capacity less than 5 MW are ignored for this analysis.

Table 15 lists the counties that have cumulative CHP resources greater than 5 MW in the 0 to 5 MW category. For example, Alameda has a cumulative total of 15 MW of CHP generators in the 0 to 5 MW category. Los Angeles County is a special case. Both SCE and LADWP have CHP generators. The Los Angeles power flow contingency analysis is completed twice. The first LA county analysis models the SCE generators under a SCE contingency simulation. The second LA county analysis models the LADWP generators under a LADWP contingency simulation. A combined Los Angeles County simulation using 164 MW of CHP generators from the 0 to 5 MW category is not completed.

Table 15: Counties with Cumulative CHP Greaten than 5 MW in 0 to 5 MW Category

County	PG&E	SCE	LADWP	SDG&E
Alameda	15			
Contra Costa	7			
Fresno	15			
Humboldt	11			
Los Angeles		126	38	
Madera	6			
Merced	12			
Orange		28		
Riverside		11		
Sacramento	12			
San Diego				16
San Bernardino		10		
San Joaquin	25			
Santa Clara	15			
Solano	7			
Sonoma	5			
Stanislaus	12			
Tehama	9			
Ventura		10		
Yolo	5			
Number of Counties	14	5	1	1

Figure 1 is a map of the counties included in the 0 to 5 MW category with cumulative megawatts of 5 MW or more. Except for Tulare, Humboldt and Sonoma counties, most of the 0 to 5 MW CHP generators are located in the California Central Valley area and the southeast corner of California. Although the entire counties of San Bernardino and Riverside counties are highlighted, the CHP generators are located in the western portion of these counties.

Figure 7: Counties that have 5 MW or more of Cumulative MW in the 0 to 5 MW Category

Table 16 shows four scenarios for each simulation; 0 to 5 MW; 5 to 20 MW; 0 to 20 MW and 0 to Greater than 20 MW. The 0 to 5 MW category is studied first then the 5 to 20 MW. The third case is the 0 to 20 MW which is the combination of the first two cases. The fourth case is all of the CHP generators from 0 MW to Greater than 20 MW. Each of these four cases is studied under the county, utility and state scenarios.

Table 16: Simulation categories County, CHP, PV size, Utility and State.

Simulation Round	County	Utility	State	0 to 5 MW	5 to 20 MW	0 to 20 MW	0 to +20 MW (ALL)
1	✓			✓	✓	✓	✓
2		✓		✓	✓	✓	✓
3			✓	✓	✓	✓	✓

Prior to simulating the power flow contingency analysis, the 2020 summer peak, spring peak and fall off-peak base cases are analyzed under steady state (N-0) conditions. The objective of the N-0 analysis is the determination of base overloads. As new generators are added to the system, there may be new transmission element overloads. The N-0 base case analysis prepares a listing of transmission element overloads to compare to the scenario overloads.

The base case power flow simulations under N-1 conditions are completed for the 2020 summer peak, spring peak and fall off-peak periods without the CHP generators installed. These three simulations provide the transmission reliability base lines for comparing potential impacts of

CHP generators on transmission reliability. The residential PV resources are included in the base case simulations as previously discussed.

For the county analysis, the CHP generator capacity is injected into the system in increments until the maximum generation is added or a new transmission element overload occurs under steady state conditions (N-0). The utility power flow simulation is completed for the first contingency (N-1) conditions for the county being studied. The first contingency analysis (N-1) is the outage of one transmission line or one generator. The total number of contingencies in each simulation is dependent upon the utility and ranges from 200 to over 5,000 simulations. As shown in Table 15, there are 21 county power flow simulations for each of the three simulation periods (14 in PG&E, 5 in SCE, 1 in LADWP and SDG&E) or a total of 63 county simulations. For each county power flow simulation, the AMWCO is recorded which is described in the next section.

Continuing with the county analysis, the next set of power flow simulations includes only those CHP generators in the 5 to 20 MW category. The CHP generators are incrementally added in each county until all of the generators are installed or an overload occurs in one or more transmission elements under N-0 conditions. A utility power flow contingency analysis is completed for each individual county scenario. The AMWCO values are recorded. There are 72 county simulations for the 5 to 20 MW category.

The next set of simulations includes all generators from 0 to 20 MW, or the first two scenarios. The same power flow simulation process is completed again for the county analysis. There are a total of 90 county simulations. The last set of simulations includes all of the CHP generators from 0 to Greater than 20 MW. Generators are added until either all of the generators are added or until an overload occurs on a transmission element. The power flow simulation is completed for each county and for the 2020 summer peak, spring peak and fall off-peak power flow data sets. There are 93 county simulations for the 0 to Greater than 20 MW. The total county power flow simulations are 318.

The next series of power flow analyses is completed for each utility. The individual utilities studied are PG&E, SCE, SDGE, LADWP and IID. For each utility, the same four scenarios (0 to 5, 5 to 20, 0 to 20 and 0 to Greater than 20 MW) are completed for the 2020 summer peak, spring peak and fall off-peak. There are 48 utilities simulations to cover the three seasons and the four different CHP categories.

The last set of power flow analyses is completed for the entire state of California. The four scenarios are studied for the three data sets. There are 12 state wide power flow simulations.

The power flow simulations for county, utility and state for the three seasons are 378. The full list of combinations is shown in Table 17 below.

Table 17: MW of CHP in each California County

PG&E				SCE			
COUNTY	**0 -5 MW**	**5 – 20 MW**	**0 - 20+ MW**	**COUNTY**	**0 -5 MW**	**5 – 20 MW**	**0 - 20+ MW**
ALAMEDA	15	35	50	KERN	0	0	159
BUTTE	0	11	11	LOS ANGELES	126	113	1433
CONTRA COSTA	7	6	177	ORANGE	28	28	56
FRESNO	15	19	93	RIVERSIDE	11	0	11
HUMBOLDT	11	10	133	SAN BERNARDINO	10	43	94
KERN	0	37	37	TULARE	0	0	114
LASSEN	0	11	11	VENTURA	10	18	52
KINGS	0	7	7	**SDG&E**			
MADERA	6	9	73	**COUNTY**	**0 -5 MW**	**5 – 20 MW**	**0 - 20+ MW**
MENDOCINO	0	16	156	SAN DIEGO	16	14	30
MERCED	12	42	301	**LADWP**			
MONTEREY	0	7	48	**COUNTY**	**0 -5 MW**	**5 – 20 MW**	**0 - 20+ MW**
PLACER	0	11	11	LOS ANGELES	38	0	1705
SACRAMENTO	12	6	18	**IID**			
SAN JOAQUIN	25	13	63	**COUNTY**	**0 -5 MW**	**5 – 20 MW**	**0 - 20+ MW**
SANTA CLARA	15	17	32	IMPERIAL	0	0	114
SANTA CRUZ	0	16	16				
SHASTA	0	4	4				
SOLANO	7	0	123				
SONOMA	5	0	5				
STANISLAUS	12	32	103				
TEHAMA	9	0	9				
YOLO	5	0	5				

5 RESULTS

5.1 2010 RESULTS

The objectives of the 2010 analysis are: (1) Determine if the existing CHP improved grid reliability; and (2) Provide a benchmark for comparing 2020 alternatives. Energy and Environmental Analysis, Inc. (EEA) provided the CHP data via their online database. A combination of maps and a bus load listing from a WECC summer 2010 power flow case is used to assign the CHP facilities to a power flow bus. In most cases, the closest bus with load and generation is used to represent the CHP facility.

For each substation with CHP, the aggregated MWs of CHP are combined. The CHP resources are load reducers so the bus loads are net load. For this analysis, CHP load and generation are represented several ways. When a CHP resource is added to a bus there is a corresponding load added to the bus equal to the CHP resource. When the CHP is simulated out of service for a contingency case, then the load at the substation automatically increases since the CHP is not available to reduce load. This representation simulates the impacts that CHP provides by reducing load on substations and transmission lines.

The figure below shows the locations of the 2010 existing CHP locations. The locations are plotted by city, and the size of the circle indicates the range of MW the site produces.

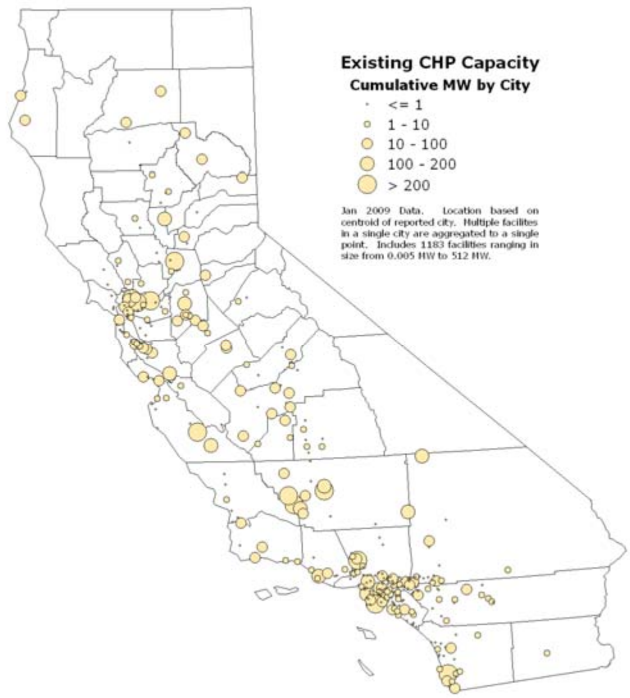


Figure 8: 2010 Existing CHP Locations cumulative MW by city

Power flow simulations are completed for three 2010 seasons: spring peak, summer peak and fall off peak. There are two power flow N-1 contingency simulations completed for each utility (PG&E, SDG&E, IID, LADWP, and SCE) and all of California combined. The two simulations are with (BASE AMWCO) and with (CHP AMWCO). For each simulation, the AMWCO, delta AMWCO and RTBR are calculated and shown in Table 18. The 2010 RTBR are all negative for each utility and state-wide except for IID. The negative RTBR values indicate a transmission benefit in reducing transmission congestions with the addition of CHP.

Table 18: Existing CHP Resource RTBR Values for 2010

Summer	Base AMWCO	CHP AMWCO	CHP IN	DELTA	RTBR
CA	29,843	7,204	8,813	-22,639	-2.6
PGE	21,900	4,467	5,885	-17,432	-3
SCE	5,670	2,196	1,738	-3,474	-2
SDGE	1,103	0	442	-1,103	-2.5
IID	249	249	8	0	0
LADWP	3,201	249	742	-2,952	-4
Spring	**Base AMWCO**	**CHP AMWCO**	**CHP IN**	**DELTA**	**RTBR**
CA	17,027	4,350	8,813	-12,677	-1.4

PGE	15,486	3,121	5,885	-12,365	-2.1
SCE	1,593	883	1,738	-711	-0.4
SDGE	4	0	442	-4	0
IID	265	269	8	4	0.6
LADWP	2,578	44	742	-2,534	-3.4
Fall	**Base AMWCO**	**CHP AMWCO**	**CHP IN**	**DELTA**	**RTBR**
CA	16,025	2,289	8,813	-13,736	-1.6
PGE	16,121	1,705	5,885	-14,416	-2.4
SCE	5,670	262	1,738	-5,408	-3.1
SDGE	16	15	442	-1	0
IID	441	451	8	10	1.3
LADWP	560	0	742	-560	-0.8

Figure 3 displays the RTBR values for three different 2010 seasons in graphical form. The utility results for PG&E, SCE, SDG&E, and LADWP are all negative indicating that the CHP resources provided a benefit to the transmission system by reducing the AMWCO. The 2010 spring and fall CHP resources for SDG&E did not exhibit a dramatic benefit. This could be attributed to low load levels and/or interchange flows. The one 7.5 MW CHP resource in the Imperial Irrigation District (IID) produced positive RTBR values in all 3 seasons.

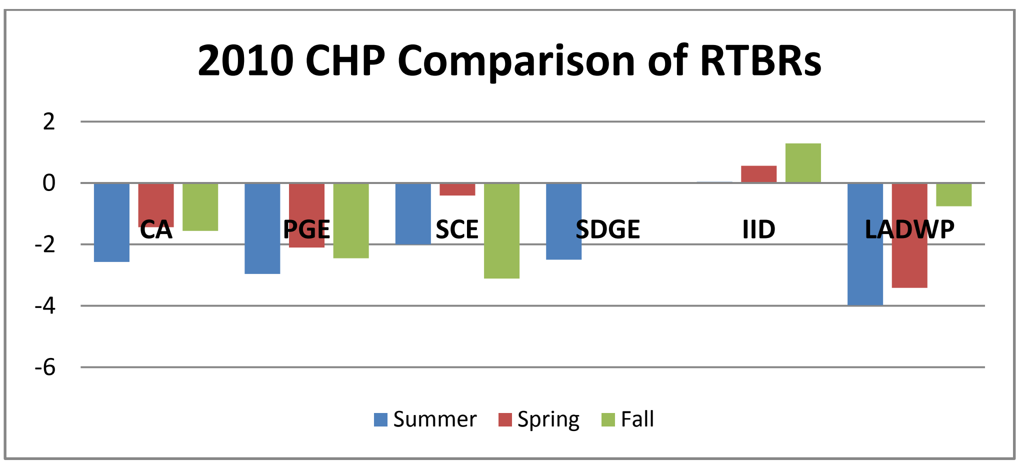


Figure 9: 2010 CHP Comparison of RTBRs

The statewide California results for 2010 CHP is not surprising. For all three seasons, the RTBR is negative. With CHP facilities being represented in each utility, collectively, this reduces the congestion on the grid and enhances overall grid reliability and stability.

5.2 2020 RESULTS

The 2020 summer peak, spring peak, and fall off peak county results are separated by the density of the population, and classified as rural or urban. Rural counties are defined by the Bureau of the Census by population density [1]. Counties with less than 1,000 people per square mile are rural, and greater than this, with a major city within the county lines, are defined as Urban. The 2020 power flow analyses are completed by county, utility and entire state of California. There are 14 counties studied in PG&E, 5 in SCE and one each in SDG&E and LADWP areas.

5.2.1 2020 Summer County Results

The results are organized by county, and filtered from most beneficial (highest negative) to most detriment (highest positive) RTBR's. The results are plotted in the following figures for PG&E, SCE and the remaining utilities. The Summer PG&E RTBR results are presented in Figure 4 and Table 19 for the "Urban" counties of PG&E for the four categories (0 to 5 MW, 5 to 20 MW, 0 to 20 MW and 0 to Greater than 20 MW).

In the PG&E urbanized counties, there are high negative RTBR's in Sacramento, Alameda, Fresno counties for certain category sizes. Sacramento County has the highest benefical RTBRs for the 0 to 5 MW, 5 to 20 MW and 0 to 20 MW categories. There are no single CHP units greater than 20 MW proposed in Sacramento so that analysis is not completed. Alameda had a high RTBR benfit ratio for the 0 to 5 MW category. Fresno County has high RTBR ratios for all four categories.

Table 19: RTBR Results for PG&E Urban Areas

PGE	URBAN COUNTIES		
COUNTY	**Category**	**CHP MW**	**RTBR**
SACRAMENTO	0 TO 5	12	-3.1
SACRAMENTO	0 TO 20	18	-2.6
ALAMEDA	0 TO 5	15	-1.67
SACRAMENTO	5 TO 20	6	-1.6
FRESNO	0 TO 5	15	-1.51
FRESNO	5 TO 20	19	-1.46
FRESNO	0 TO 20	34	-1.38
FRESNO	0 TO 20+	93	-0.87
SANTA CLARA	0 TO 5	15	-0.6
SANTA CLARA	5 TO 20	17	-0.6
SANTA CLARA	0 TO 20	32	-0.6
ALAMEDA	0 TO 20	50	-0.09
CONTRA COSTA	0 TO 20+	197	-0.02
CONTRA COSTA	0 TO 20	13	0.16
CONTRA COSTA	0 TO 5	7	0.2
CONTRA COSTA	5 TO 20	6	0.38
ALAMEDA	5 TO 20	35	0.46

The RTBR results can be easily seen in Figure 4 below. Although Santa Clara County has a negative RTBR, the value is low compared to the more beneficial areas.

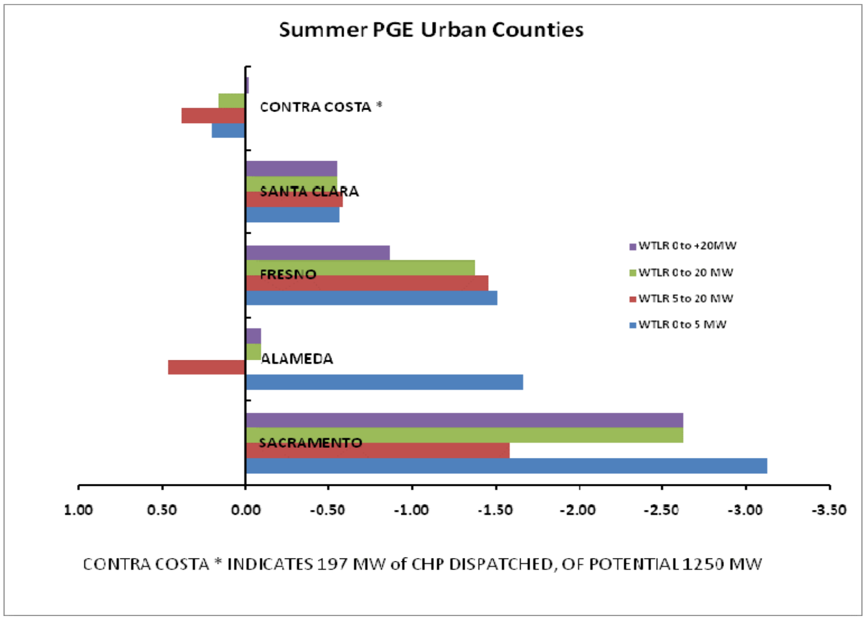


Figure 10: 2020 Summer PGE Urban counties

As discussed before, the CHP resources were divided into urban and rural. Table 20 displays the RTBR results for the PG&E rural areas. The counties that are the best locations for CHP resources are San Joaquin, Sonoma, Solano, Stanislaus, Merced, Placer and Kings Counties. The RTBR benefits in all categories occurred in San Joaquin County. Any development in any of the categories is benefical to San Joaquin County. In the seven counties with the best RTBR, the category providing the best RTBR benefits is the 0 to 5 MW. The 5 to 20 MW category provides the best RTBR benefits to Kings and Placer Counties.

The two counties with positive RTBR indicating that the addition of CHP is a detriment to transmission reliability are Mendocino and Hunboldt. The "*" indicates that the full CHP potential could not be installed and that even a small CHP penetration caused transmission congestion.

Table 20: RTBR Results for the PG&E Rural Counties

PG&E RURAL COUNTY	Category	CHP MW	RTBR	PG&E RURAL COUNTY	Category	CHP MW	RTBR
SAN JOAQUIN	0 to 5	25	-3.42	MERCED	5 to 20	42	-0.43
SONOMA	0 to 5	5	-2.74	MERCED	0 to +20	301	-0.36
SAN JOAQUIN	0 to 20	38	-2.37	SANTA CRUZ	5 to 20	16	-0.29
SOLANO	0 to 5	7	-2.09	KERN	5 to 20	37	-0.26
SAN JOAQUIN	0 to +20	63	-1.92	MADERA	0 to +20	73	-0.25
SAN JOAQUIN	5 to 20	13	-1.48	MONTEREY	5 to 20	7	-0.1
STANISLAUS	0 to 5	12	-1.26	MADERA	5 to 20	9	-0.04

PG&E RURAL COUNTY	Category	CHP MW	RTBR	PG&E RURAL COUNTY	Category	CHP MW	RTBR
MERCED	0 to 5	12	-1.18	MADERA	0 to 20	16	-0.03
PLACER	5 to 20	11	-1.13	MADERA	0 to 5	6	-0.02
KINGS	5 to 20	7	-1.01	HUMBOLDT *	0 to 5	11	0.08
SOLANO	0 to +20	123	-0.61	MENDOCINO *	0 to +20	156	0.16
STANISLAUS	0 to 20	44	-0.61	MENDOCINO *	5 to 20	16	0.23
STANISLAUS	5 to 20	32	-0.59	HUMBOLDT *	5 to 20	10	0.27
LASSEN	5 to 20	11	-0.49	HUMBOLDT *	0 to 20	21	0.31
MERCED	0 to 20	54	-0.45	MONTEREY	0 to +20	63	0.38
STANISLAUS	0 to +20	103	-0.45	HUMBOLDT *	0 to +20	135	0.69

The results for Summer PG&E rural counties are graphed in Figure 5. It can easily be seen that Mendocino and Hunboldt had all positive RTBRs. The remaining counties had netural RTBR results. If CHP is installed in these counties, the major benefits may come from ancillary services and regulation services in these rural areas.

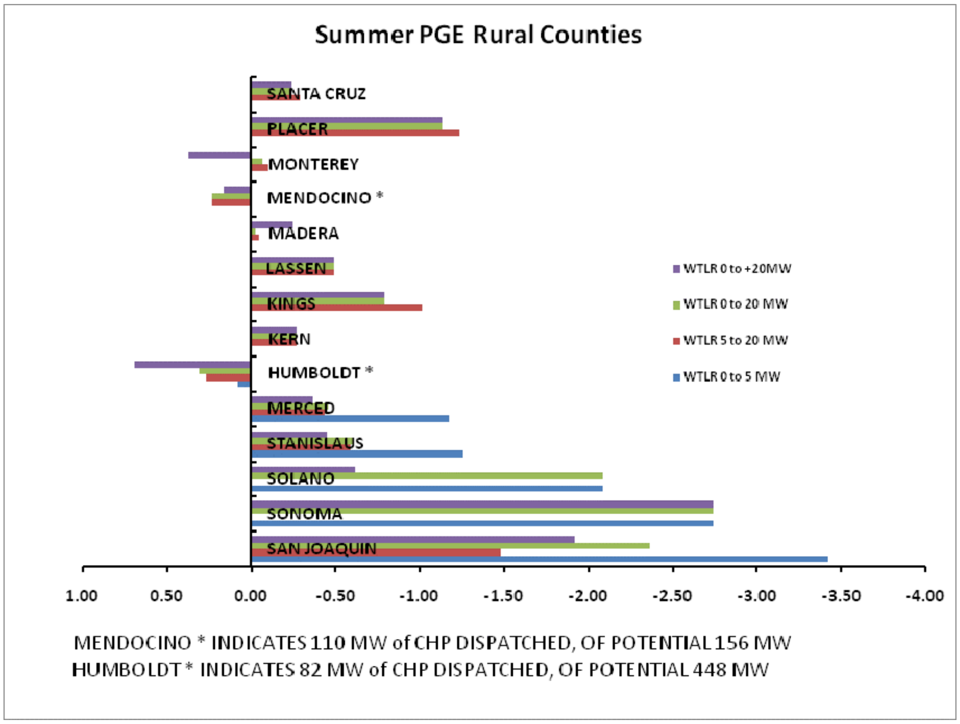


Figure 11: Rural Counties in PG&E 2020 Summer

Even when combined together, SCE, IID, LADWP and SDG&E have significantly fewer counties with potential CHP resources than PG&E. The total megawatts of CHP resources in Los Angeles County are 3,138 MW that is more than all of the CHP resources in the PG&E area. Los Angeles County is served by both SCE and LADWP and is therefore shown twice in the table below.

Table 21 displays the RTBR results for the southern California utilities. For SCE, all of the scenarios have beneficial results although the RTBR values do not exceed -1.0. For the other utilities, the RTBR are all small negative values except for Los Angeles County served by LADWP that has a RTBR of 0.63. The RTBR values are so small that installing CHP resources are neither beneficial nor detrimental to the transmission system.

Table 21: 2020 Summer Urban RTBR for Southern California Utilities

SCE	**URBAN COUNTIES**		
COUNTY	**Category**	**CHP MW**	**RTBR**
Los Angeles (SCE)	5 to 20	113	-0.97
Los Angeles (SCE)	0 to 20	239	-0.91
Los Angeles (SCE)	0 to 5	126	-0.87
Orange	0 to 5	28	-0.32
Los Angeles (SCE)	0 TO 20+	1,433	-0.3
Orange	0 to 20	56	-0.26
Orange	5 to 20	28	-0.25
Riverside	0 to 5	11	-0.13
Other Utilities			
COUNTY	**Category**	**CHP MW**	**RTBR**
San Diego (SDGE)	5 to 20	14	-0.75
San Diego (SDGE)	0 to 20	30	-0.53
San Diego (SDGE)	0 to 5	16	-0.47
Los Angeles (LADWP)	0 to 5	38	-0.27
Imperial (IID)	0 TO 20+	114	-0.02
Los Angeles (LADWP)	0 TO 20+	1,705	0.63

Figure 6 below shows the RTBR for all of the 2020 summer urban CHP scenarios for the southern California utilities. The RTBR scale does not exceed -1.0.

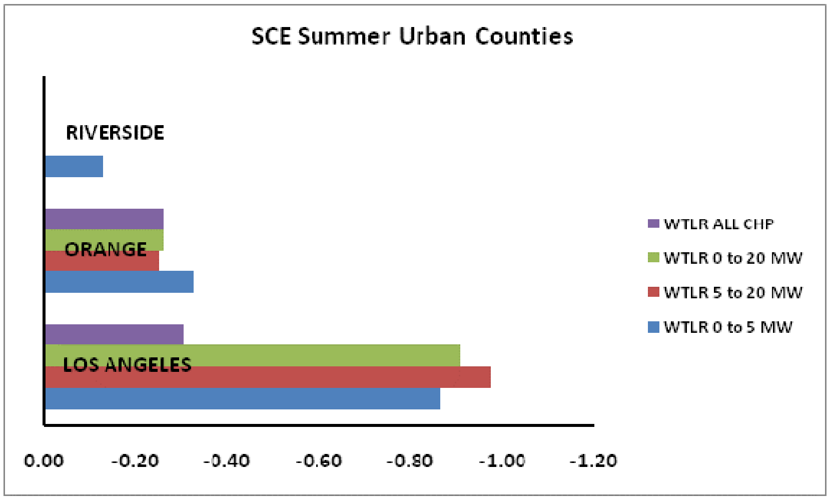


Figure 12: Summer SCE Urban counties

SCE is the only southern California utility with rural counties as shown on Table 22 and Figure 7. The installation of CHP resources produces positive RTBR values in Kern, Tulare, and Ventura Counties. The RTBR values for the remaining CHP scenarios are neither beneficial nor detrimental. Ventura County has the highest positive RTBR values. Any CHP scenario greater than the 0 to 5 MW has a significant impact on the transmission system.

Table 22: 2020 RTBR Rural County Results for Southern California Utilities

SCE	RURAL COUNTIES		
COUNTY	**Category**	**CHP MW**	**RTBR**
San Bernardino	0 to 5	10	-0.49
Ventura	0 to 5	10	-0.18
San Bernardino	5 to 20	43	-0.17
San Bernardino	0 to 20	53	-0.16
Tulare	0 TO 20+	114	0.84
Kern	0 TO 20+	159	1.53
San Bernardino	0 TO 20+	94	2.39
Ventura	0 TO 20+	52	6.07
Ventura	0 to 20	28	11.54
Ventura	5 to 20	18	17.99

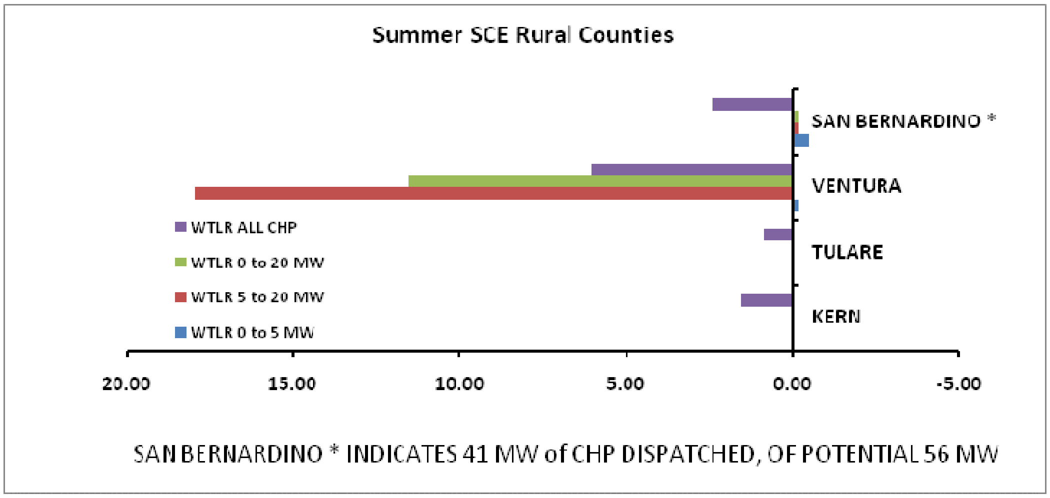
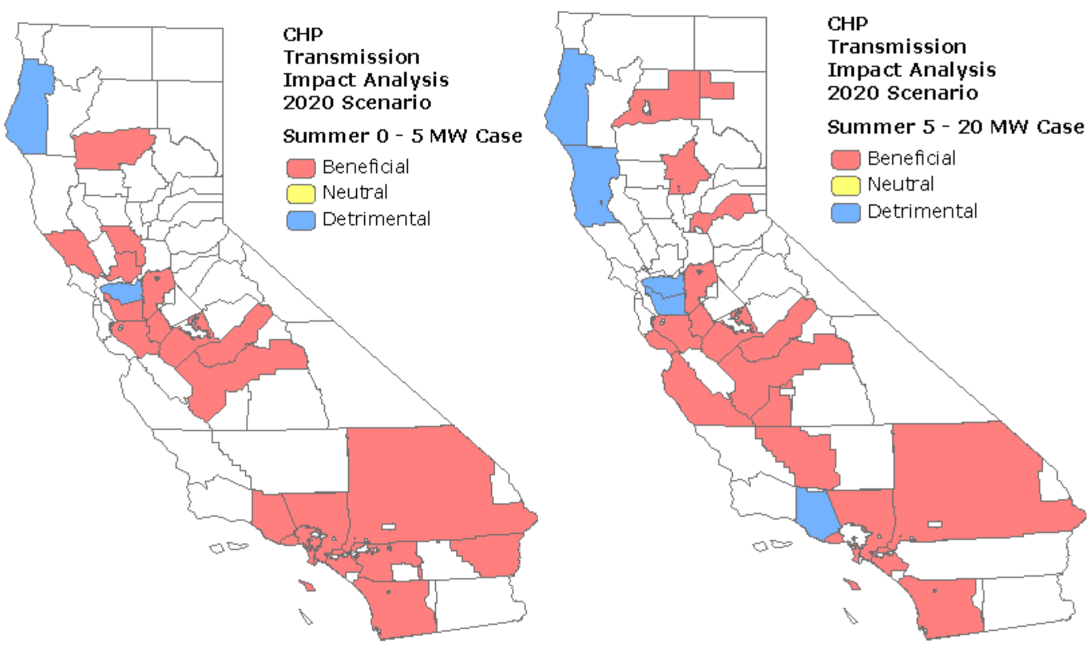
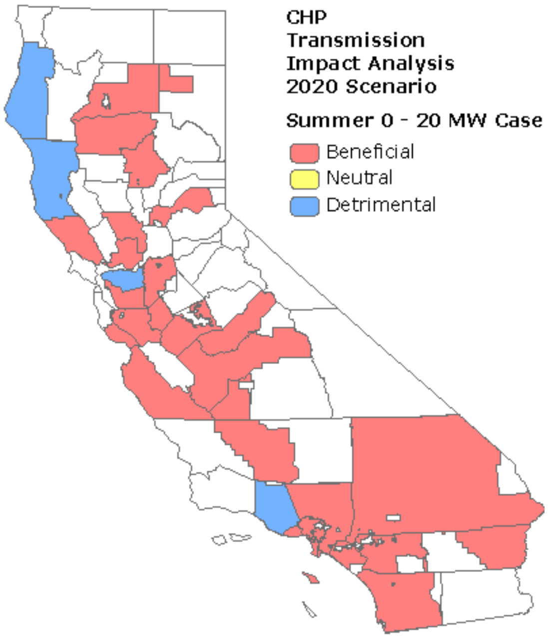


Figure 13: Summer SCE rural counties

The county results are plotted geographically for the whole state for Summer, by size range 0 to 5 MW, red indicates a beneficial effect in the marked county, yellow is neutral, and blue is detrimental (Figure 8). White indicates the county either did not have any CHP or did not have any in the category considered.





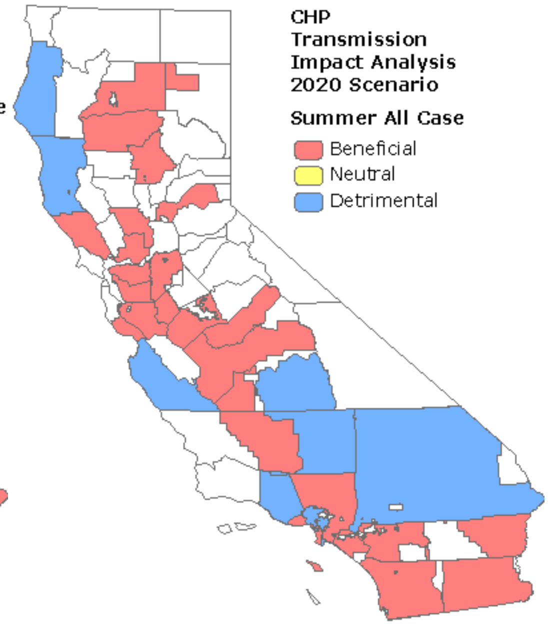


Figure 14 Summer RTBR all California counties for 0 to 5 MW (Top LHS), 5 to 20 MW (Top RHS), 0 to 20 MW (Bottom LHS), and All (Bottom RHS)

5.2.2 2020 Spring County Results

The formats for the spring and fall RTBR results are the same as for the summer analysis. The RTBR results are displayed in both tabular and graphical form. The spring power flow data sets have high hydroelectric generation within California and high imports from the Pacific Northwest from hydroelectric power purchases. The California system loads are low since there is neither air conditioning nor heating loads.

As shown in Table 23, Alameda County has a high negative RTBR of -1.32 for the 0 to 5 MW scenario. Contra Costa County has a high positive RTBR of 1.97 for the 0 to Greater than 20 MW scenario. In the other scenarios, the installation of CHP resources produce no significant transmission benefits except for the scenarios discussed above.

Table 23: 2020 PG&E Spring Urban RTBR Results

PGE	URBAN COUNTIES		
COUNTY	Category	CHP MW	RTBR
ALAMEDA	0 TO 5	15	-1.32
FRESNO	0 TO 5	15	-0.54
ALAMEDA	0 TO 20	50	-0.43
SACRAMENTO	0 TO 20	18	-0.39
SACRAMENTO	0 TO 5	12	-0.36
CONTRA COSTA	0 TO 20	13	-0.28
SACRAMENTO	5 TO 20	6	-0.2
SANTA CLARA	0 TO 5	15	-0.18
CONTRA COSTA	5 TO 20	6	-0.14
CONTRA COSTA	0 TO 5	7	-0.11
SANTA CLARA	5 TO 20	17	-0.1
SANTA CLARA	0 TO 20	32	-0.1
ALAMEDA	5 TO 20	35	-0.08
FRESNO	5 TO 20	19	0.03
FRESNO	0 TO 20	34	0.03
FRESNO	0 TO 20+	93	0.06
CONTRA COSTA	0 TO 20+	197	1.97

Figure 9 compares the 2020 spring PG&E urban RTBR results in graphical form. The two extreme scenarios for Contract Costa and Alameda Counties can be easily seen as compared to the other scenarios.

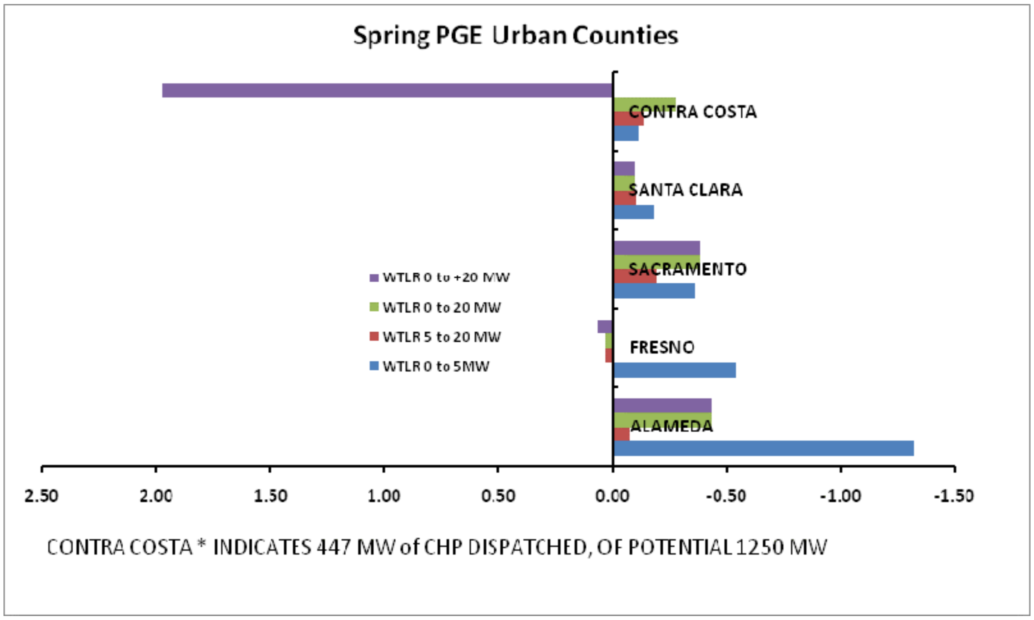


Figure 15: Spring PG&E Urban Counties

The RTBR results for the PG&E rural counties are shown in Table 24 and Figure 9. Kern and Placer Counties are consistent with the summer results in that these counties have high negative RTBR values and remain good areas for CHP development. Humboldt and Mendocino Counties continue to have positive RTBR values that are consistent with the summer results.

Table 24: PG&E 2020 Spring RTBR by County

PG&E RURAL COUNTY	Category	CHP MW	RTBR	PG&E RURAL COUNTY	Category	CHP MW	RTBR
KERN	5 to 20	37	-2	MADERA	0 to +20	73	-0.07
PLACER	5 to 20	11	-1.19	MONTEREY	5 to 20	7	-0.04
MADERA	0 to 5	6	-0.74	MADERA	5 to 20	9	-0.03
KINGS	5 to 20	7	-0.73	MERCED	5 to 20	42	-0.02
STANISLAUS	0 to 5	12	-0.61	SANTA CRUZ	5 to 20	16	-0.02
MADERA	0 to 20	16	-0.48	SOLANO	0 to +20	123	0
MERCED	0 to 5	12	-0.37	MERCED	0 to 20	54	0
STANISLAUS	0 to 20	44	-0.2	LASSEN	5 to 20	11	0.01
STANISLAUS	0 to +20	103	-0.2	MONTEREY	0 to +20	63	0.03
SAN JOAQUIN	5 to 20	13	-0.18	MERCED	0 to +20	301	0.05
SAN JOAQUIN	0 to 5	25	-0.17	MENDOCINO *	0 to +20	156	0.09
SONOMA	0 to 5	5	-0.12	MENDOCINO *	5 to 20	16	0.14
SAN JOAQUIN	0 to 20	38	-0.12	HUMBOLDT *	5 to 20	10	0.61
SOLANO	0 to 5	7	-0.12	HUMBOLDT *	0 to 20	21	0.67
STANISLAUS	5 to 20	32	-0.09	HUMBOLDT *	0 to 5	11	0.71

PG&E RURAL COUNTY	Category	CHP MW	RTBR	PG&E RURAL COUNTY	Category	CHP MW	RTBR
SAN JOAQUIN	0 to +20	63	-0.07	HUMBOLDT *	0 to +20	135	1.33

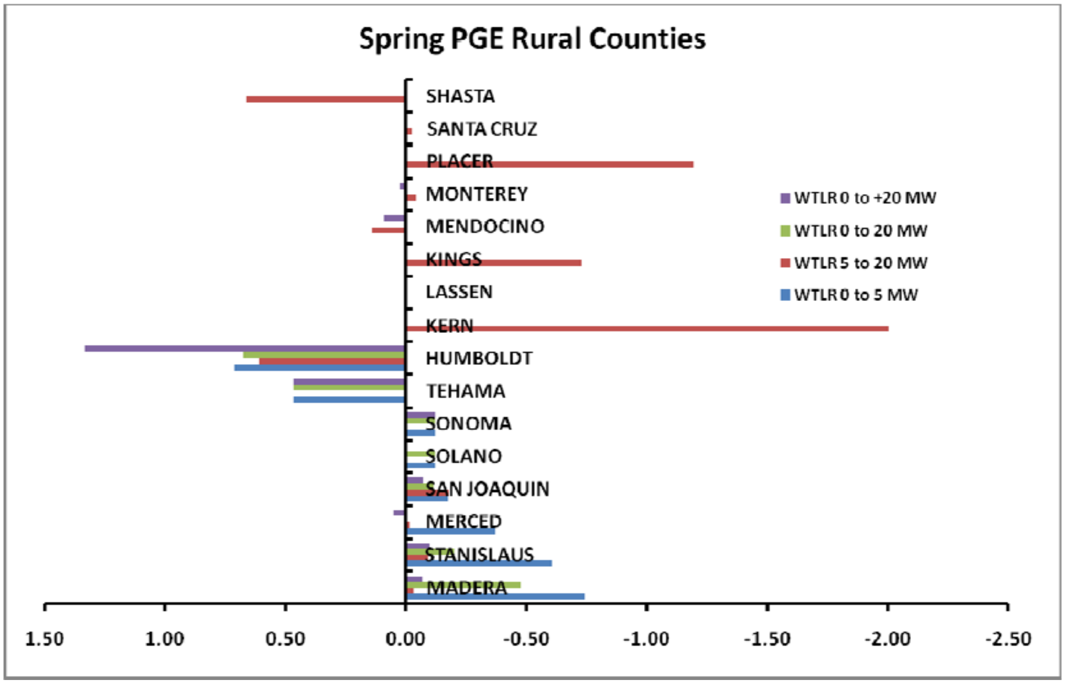


Figure 16: Spring PG&E rural counties

The SCE, IID, LADWP and SDG&E urban spring RTBR results are shown in Table 25 and Figure 10. The spring urban results are consistent with the summer results. The RTBR values vary between 0 and -0.5 for all scenarios. The injection of CHP resources are neither benefical or detrimental to transmission grid reliability.

Table 25: 2020 Spring Southern California Urban RTBR Results

SCE	URBAN COUNTIES		
COUNTY	**Category**	**CHP MW**	**RTBR**
Los Angeles (SCE)	5 to 20	113	-0.5
Los Angeles (SCE)	0 to 20	239	-0.24
Orange	0 to 5	28	-0.08
Orange	0 to 20	56	-0.04
Los Angeles (SCE)	0 to 5	126	-0.03
Riverside	0 to 5	11	-0.03

SCE	URBAN COUNTIES		
COUNTY	**Category**	**CHP MW**	**RTBR**
Orange	5 to 20	28	-0.01
Los Angeles (SCE)	0 TO 20+	1,433	0.15
Other Utilities			
COUNTY	**Category**	**CHP MW**	**RTBR**
Imperial (IID)	0 TO 20+	114	-0.02
San Diego (SDGE)	5 to 20	14	0
San Diego (SDGE)	0 to 20	30	0
San Diego (SDGE)	0 to 5	16	0
Los Angeles (LADWP)	0 to 5	38	0
Los Angeles (LADWP)	0 TO 20+	1,705	0

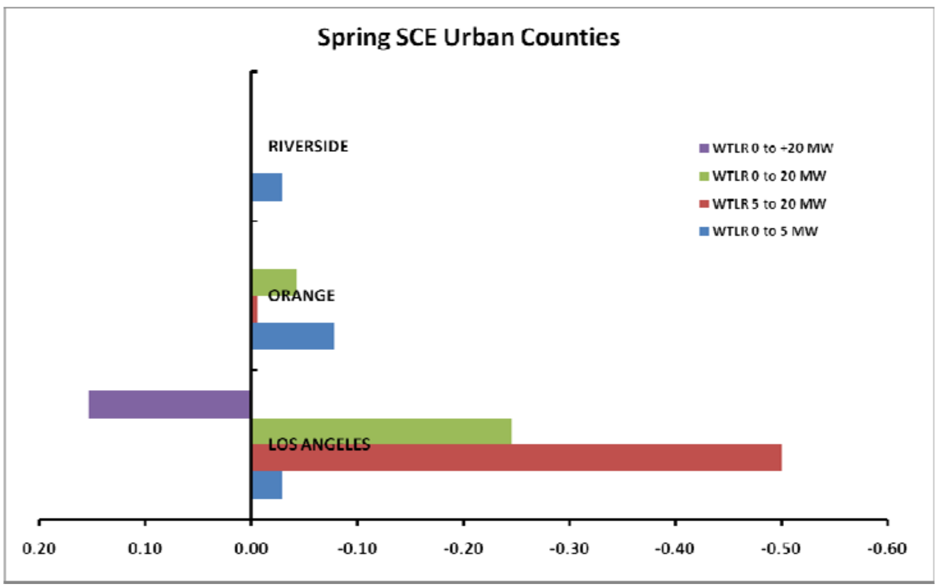


Figure 17: Spring SCE Urban Counties

The SCE rural county RTBR results are shown in Table 26 and Figure 12. In the summer results, Ventura County has high positive RTBR results but in the spring RTBR results, the values are negative. This indicates that the CHP resources have a detrimental impact during the summer peak period but a beneficial impact in the spring period. Because of the extremely high positive RTBR values in the summer as compare to the RTBR spring values, the spring results do not change the CHP value in improving transmission grid reliability. The injection of CHP resources in San Bernardino County produces negative RTBR values except for the 0 to Greater than 20 MW scenario. The injection of CHP resources greater than 20 MW is detrimental to transmission reliability.

Table 26: 2020 SCE Rural County RTBR Results

SCE	RURAL COUNTIES		
COUNTY	Category	CHP MW	RTBR
Ventura	5 to 20	18	-2.2
Ventura	0 to 20	28	-1.41
Ventura	0 TO 20+	52	-0.76
San Bernardino	0 to 5	10	0
Ventura	0 to 5	10	0
Tulare	0 TO 20+	114	0
San Bernardino	5 to 20	43	0.01
San Bernardino	0 to 20	53	0.01
Kern	0 TO 20+	159	0.36
San Bernardino	0 TO 20+	94	1.89

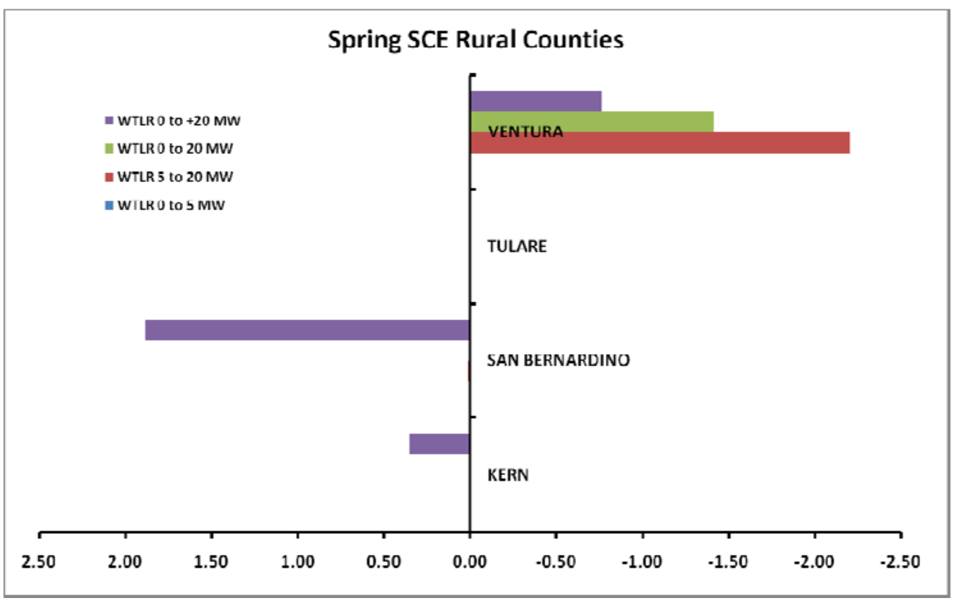


Figure 18: 2020 SCE Rural County RTBR Results

The county results are plotted geographically for the whole state for Spring, by size range 0 to 5 MW, red indicates a beneficial effect in the marked county, yellow is neutral, and blue is detrimental (Figure 14). White indicates the county either did not have any CHP or did not have any in the particular size category considered.

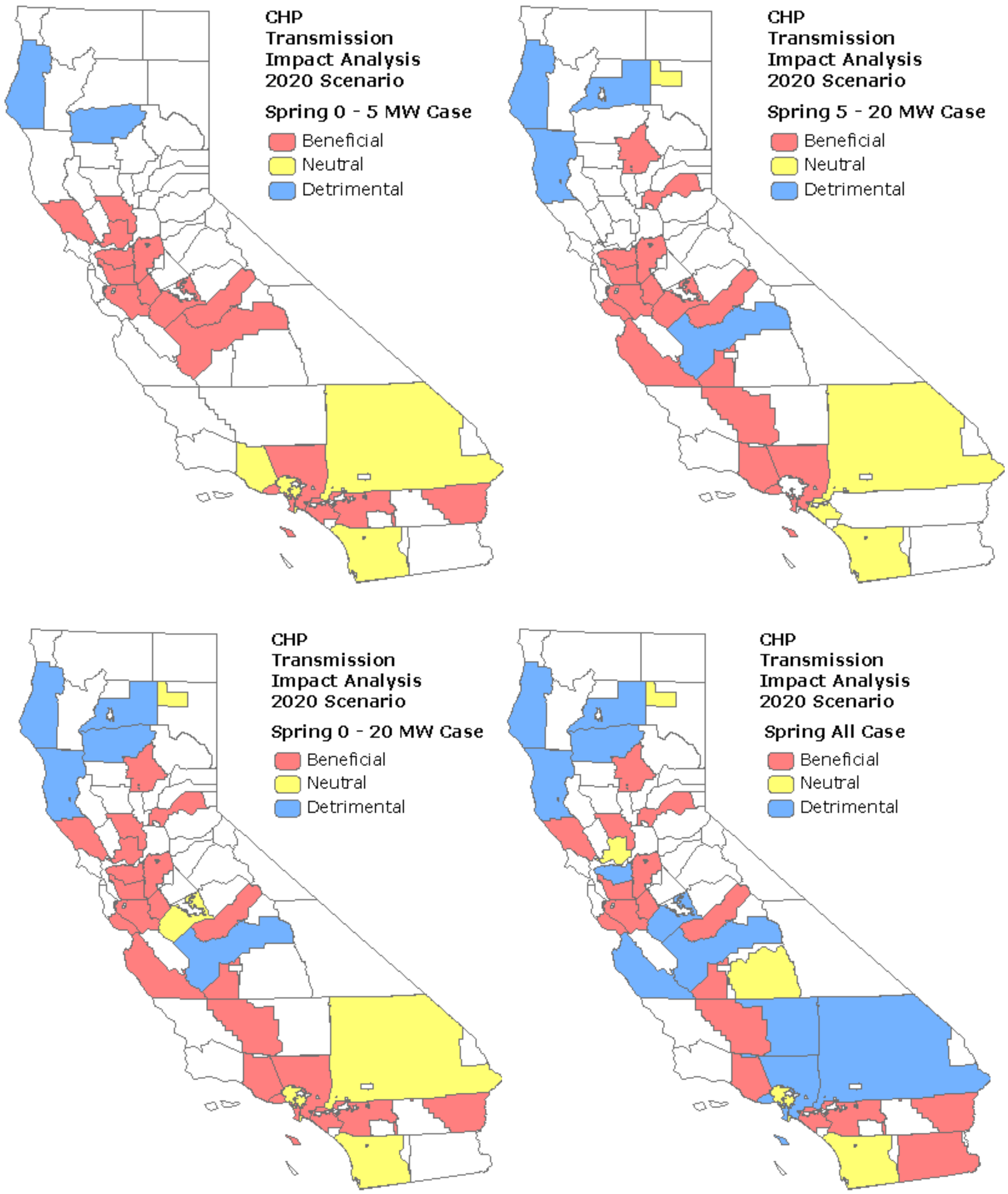


Figure 19 Spring RTBR all California counties for 0 to 5 MW (Top LHS), 5 to 20 MW (Top RHS), 0 to 20 MW (Bottom LHS), and All (Bottom RHS)

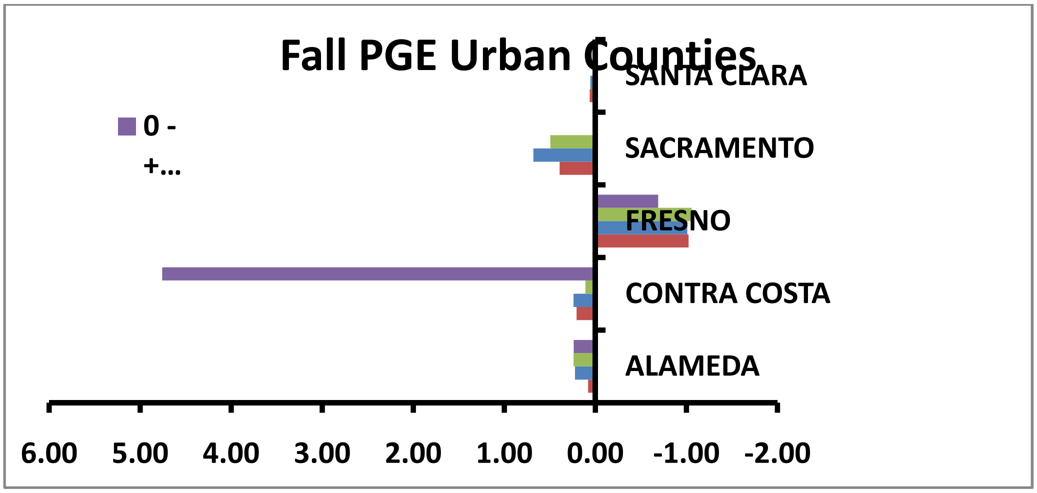
5.2.3 2020 Fall Count Results

The fall power flow results stress the system since the time period is a fall off-peak fall period (2 am in the morning). The system loads are at minimum, the hydroelectric generation is at minimum since the reservoirs are at the lowest levels, PV generation is off-line and there are high power transfers between the Desert Southwest and the Pacific Northwest. Table 27 and Figure 14 show the RTBR results for the fall PG&E rural counties.

Table 27: 2020 PGE Urban County RTBR Results

PG&E URBAN COUNTY	Category	CHP MW	RTBR
ALAMEDA	0 -5	15	0.08
ALAMEDA	5 - 20	35	0.23
ALAMEDA	0 - 20	50	0.24
ALAMEDA	0 - +20	50	0.24
CONTRA COSTA	0 -5	7	0.21
CONTRA COSTA	5 - 20	6	0.24
CONTRA COSTA	0 - 20	13	0.11
CONTRA COSTA	0 - +20	177	4.76
FRESNO	0 -5	15	-1.02
FRESNO	5 - 20	19	-1.01
FRESNO	0 - 20	34	-1.06
FRESNO	0 - +20	93	-0.69
SACRAMENTO	0 -5	12	0.39
SACRAMENTO	5 - 20	6	0.68
SACRAMENTO	0 - 20	18	0.50
SACRAMENTO	0 - +20	18	0.00
SANTA CLARA	0 -5	15	0.06
SANTA CLARA	5 - 20	17	0.06
SANTA CLARA	0 - 20	32	0.02
SANTA CLARA	0 - +20	32	0.02

Figure 20: 2020 PGE Urban County RTBR Results



In the 2020 Fall Case, the only urban county to benefit from CHP is Fresno County. Fresno contains all sizes of CHP. There are detrimental impacts to every other urban county in PG&E area. Contra Costa is the most detrimentally affected in Fall, Urban PG&E counties and has CHP resources in all of the categories.

Table 28 and Figure 15 show the RTBR results for the fall PG&E rural counties. Kern, Madera and King Counties continue to demonstrate RTBR benefits for all three seasons in certain scenarios as shown below. Humboldt and Mendocino counties continue to have positive RTBR indicating that any CHP development causes transmission problems in the counties. Humboldt County did not have the full potential of CHP resources dispatched due to transmission overloads; 92 MW out of 448 MW in Humboldt County. The remaining counties continue to have RTBR values that are close to zero indicating that the CHP injection has little impact on transmission reliability.

Table 28: PG&E 2020 Rural County RTBR Results

PG&E RURAL COUNTY	Category	CHP MW	RTBR	PG&E RURAL COUNTY	Category	CHP MW	RTBR
KERN	5 to 20	37	-2.28	SAN JOAQUIN	0 to 20	38	0.06
MADERA	5 to 20	9	-2.18	SOLANO	0 to +20	123	0.06
MADERA	0 to +20	73	-2.07	SANTA CRUZ	5 to 20	16	0.07
MADERA	0 to 20	16	-1.77	SONOMA	0 to 5	5	0.09
KINGS	5 to 20	7	-1.36	STANISLAUS	0 to 5	12	0.1
MADERA	0 to 5	6	-1.32	PLACER	5 to 20	11	0.1
MERCED	0 to +20	301	-0.44	MONTEREY	0 to +20	63	0.1
MERCED	5 to 20	42	-0.4	MERCED	0 to 5	12	0.11
MERCED	0 to 20	54	-0.31	SOLANO	0 to 5	7	0.12

PG&E RURAL COUNTY	Category	CHP MW	RTBR	PG&E RURAL COUNTY	Category	CHP MW	RTBR
LASSEN	5 to 20	11	0	SAN JOAQUIN	5 to 20	13	0.13
STANISLAUS	0 to +20	103	0	MENDOCINO *	0 to +20	156	0.32
STANISLAUS	0 to 20	44	0.01	MENDOCINO *	5 to 20	16	0.54
MONTEREY	5 to 20	7	0.01	HUMBOLDT *	0 to 20	21	1.61
STANISLAUS	5 to 20	32	0.04	HUMBOLDT *	0 to 5	11	1.68
SAN JOAQUIN	0 to +20	63	0.05	HUMBOLDT *	5 to 20	10	1.68
SAN JOAQUIN	0 to 5	25	0.06	HUMBOLDT *	0 to +20	135	2.28

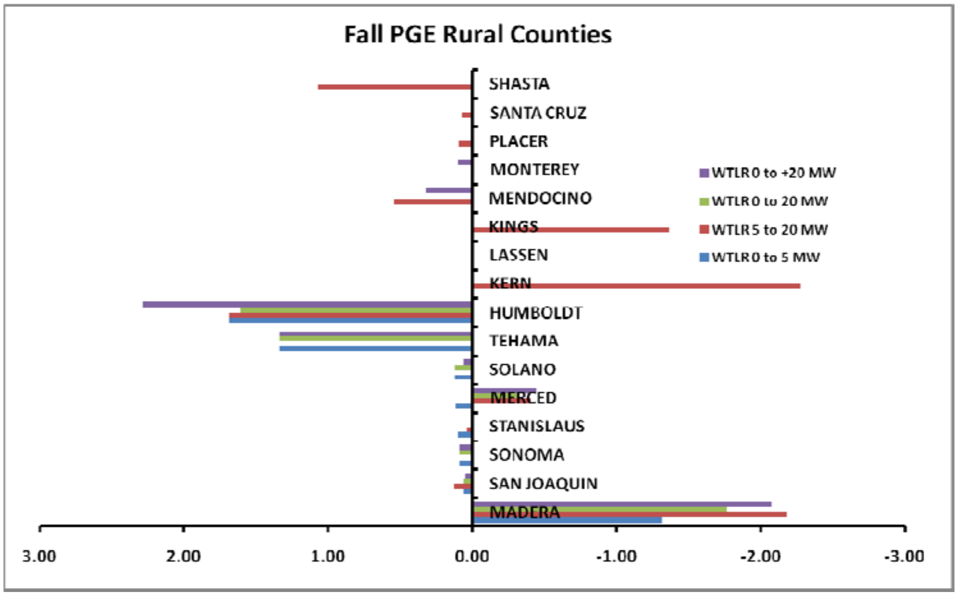


Figure 21: Fall PG&E Rural counties

Table 29 shows the RTBR results for the SCE, IID, LADWP and SDG&E urban counties. As shown in the table, the RTBR values are close to zero for all of the counties indicating that the CHP resources have little impact on transmission reliability. The RTBR values are so small that the results are not graphed.

Table 29: Southern California Utilities Urban RTBR Results

SCE	URBAN COUNTIES		
COUNTY	**Category**	**CHP MW**	**RTBR**
Los Angeles (SCE)	0 to 5	126	-0.06
Los Angeles (SCE)	0 to 20	239	-0.03
Los Angeles (SCE)	0 TO 20+	1,433	-0.01
Los Angeles (SCE)	5 to 20	113	0
Orange	0 to 5	28	0
Orange	0 to 20	56	0
Orange	5 to 20	28	0
Riverside	0 to 5	11	0
Other Utilities			
COUNTY	**Category**	**CHP MW**	**RTBR**
San Diego (SDGE)	5 to 20	14	0
San Diego (SDGE)	0 to 20	30	0
San Diego (SDGE)	0 to 5	16	0
Los Angeles (LADWP)	0 to 5	38	0
Los Angeles (LADWP)	0 TO 20+	1,705	0
Imperial (IID)	0 TO 20+	114	0.5

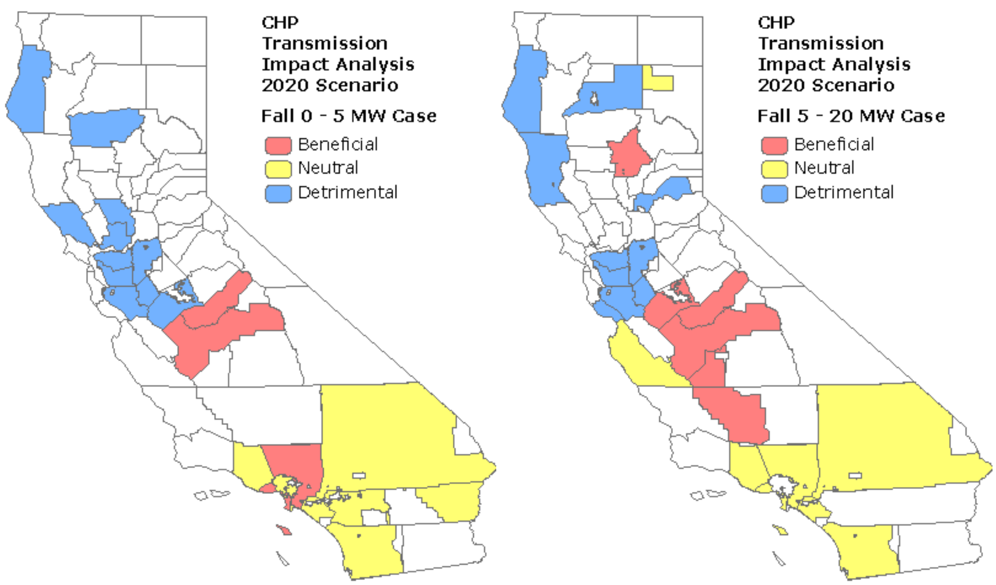
Table 30 shows the RTBR results for the SCE rural counties. The RTBR values are also close to zero for all counties. Since the values for the southern California urban and rural counties are so low, a graphical display is not developed.

Table 30: SCE Counties 2020 RTBR Results

SCE	RURAL COUNTIES		
COUNTY	**Category**	**CHP MW**	**RTBR**
Tulare	0 TO 20+	114	-0.01
Ventura	0 TO 20+	52	-0.01
Ventura	0 to 20	28	-0.01
Ventura	5 to 20	18	-0.01
San Bernardino	0 to 5	10	0
San Bernardino	0 to 20	53	0
Kern	0 TO 20+	159	0
Ventura	0 to 5	10	0.01

SCE	RURAL COUNTIES		
COUNTY	Category	CHP MW	RTBR
San Bernardino	5 to 20	43	0.01
San Bernardino	0 TO 20+	94	0.34

The county results are plotted geographically for the whole state for Fall, by size range 0 to 5 MW, red indicates a beneficial effect in the marked county, yellow is neutral, and blue is detrimental (Figure 18). White indicates there was either no CHP in that county or none in the category considered.



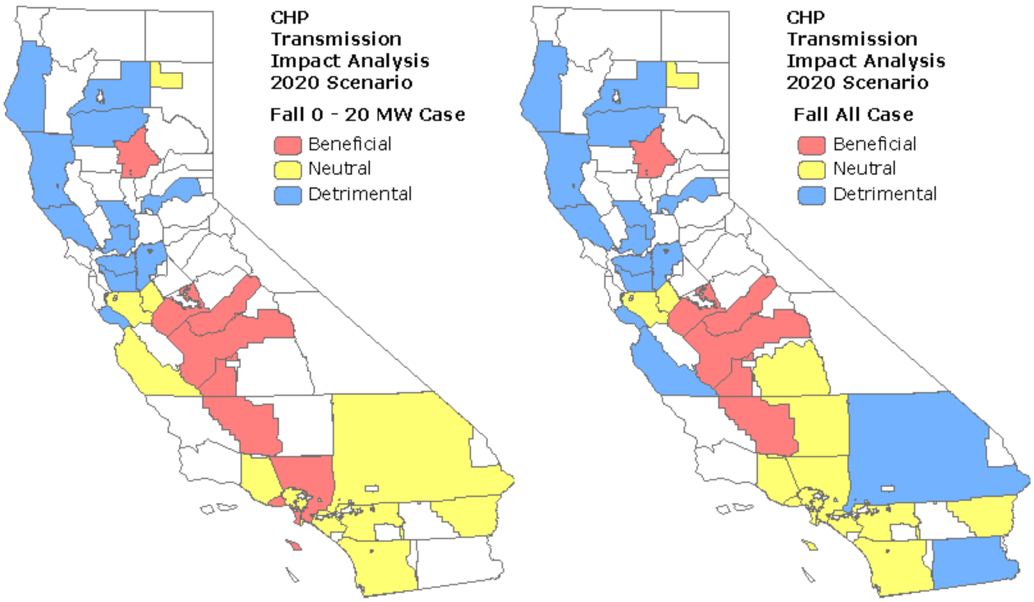


Figure 22: Fall RTBR all California counties for 0 to 5 MW (Top LHS), 5 to 20 MW (Top RHS), 0 to 20 MW (Bottom LHS), and All (Bottom RHS) California Utility Results

The simulations are conducted at the utility level as per simulation Round 2 in Table 16. The transmission reliability results (RTBR) are displayed in graphical form for each utility, and size category of CHP, for 2020 Summer, Spring and Fall. PG&E is presented first (Figure 17) followed by SCE (Figure 18), LADWP (Figure 19), IID (Figure 20), and SDG&E (Figure 21).

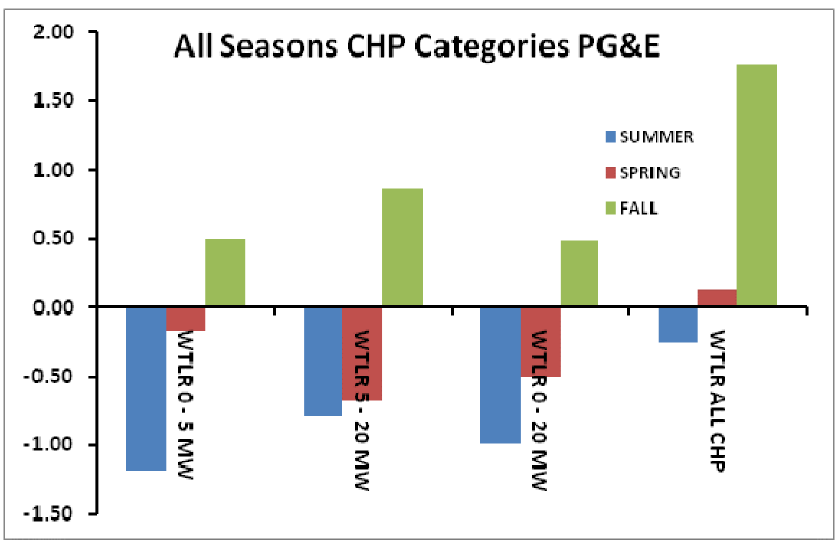


Figure 23: Summer, Spring and, Fall PGE CHP Categories

In the 2020 summer peak, PG&E experiences a transmission grid benefit from the addition of CHP in every CHP category. The most beneficial size category for PG&E is the 0 to 5 MW followed by the 0 and 20 MW category. Combining all the units in the 0 to Greater than 20 MW category is also beneficial to PG&E in the summer cases, but not as beneficial as the other smaller categories with no units greater than 20 MW, with a RTBR of -0.2, with all generation dispatched, and -1.2, with just the 0 to 5 MW category.

In the 2020 spring, there is a transmission benefit from the 0 to 5 MW category, 5 to 20 MW category and the 0 to 20 MW category, with 191 MW, 309 MW and 500 MW dispatched in each category. When the Greater than 20 MW category is dispatched (1,521 MW total), the transmission reliability decreases with a RTBR of positive 0.1.

In the fall season, there is no benefit to transmission reliability for any of the categories of CHP.

In SCE, the only transmission grid benefit in all three seasons is the dispatch of the 0 to 5 MW category which has a RTBR of -0.7. In both the 5 to 20 MW category and the 0 to 20 MW category, the summer RTBR are. With the inclusion of the Greater than 20 MW category, the impact reduces, but there is still a slightly positive RTBR. In the 2020 spring, there is a transmission benefit from all of the CHP categories except for the 0 to Greater than 20 MW category. There is minimal transmission impact from CHP generators in all cases.

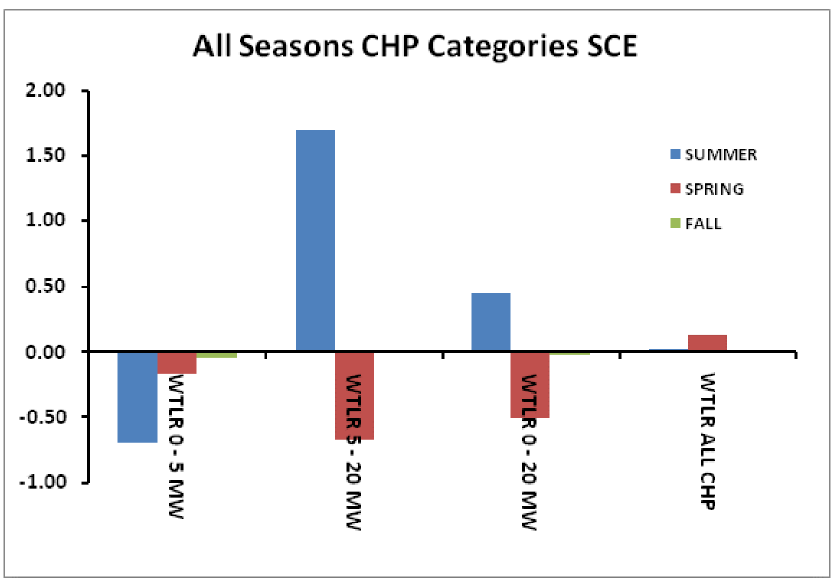


Figure 24: Summer, Spring and, Fall SCE CHP Categories

For the LADWP 2020 summer peak, the dispatch in the 0 to 5 MW category results in a transmission benefit of a negative RTBR of -0.25. There are no transmission benefits for any other category or season.

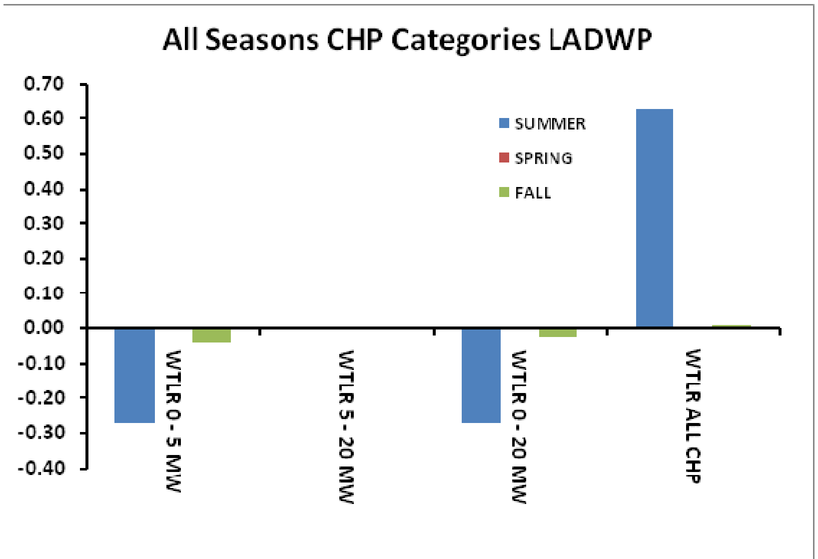


Figure 25: Summer, Spring and, Fall LADWP CHP Categories

The addition of CHP generation in the IID area resulted in no benefits for any category or season.

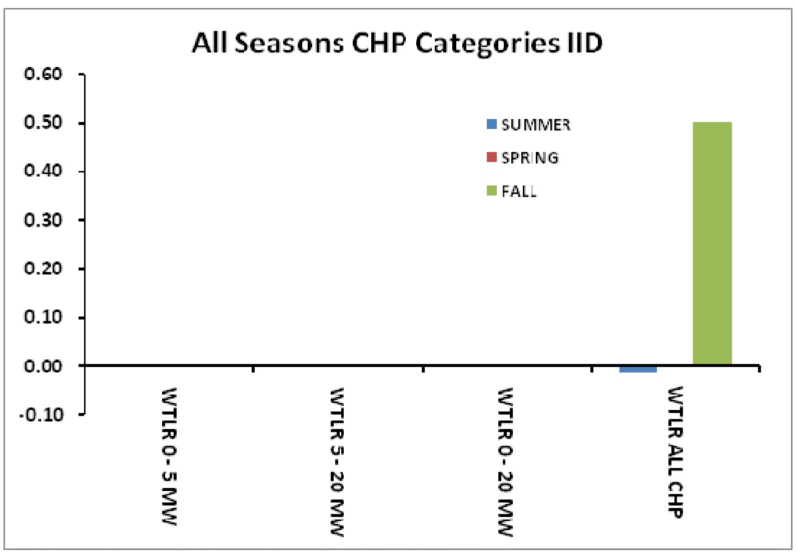


Figure 26: Summer, Spring and, Fall IID CHP Categories

There are no CHP generators in the Greater than 20 MW category. The most beneficial category in SDG&E is the 5 to 20 MW category with a negative RTBR of -0.75. Overall the RTBR shows a transmission benefit on the SDGE grid in summer but no benefit during any of the other seasons.

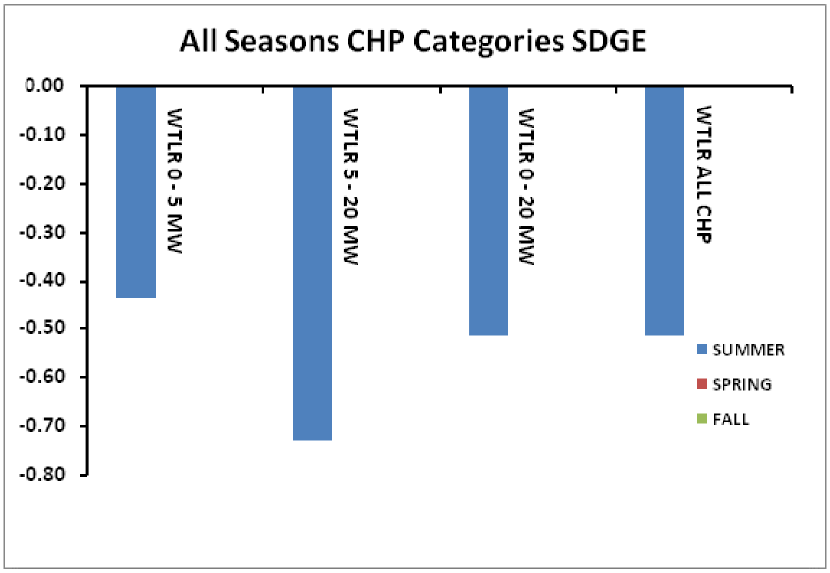


Figure 27: Summer, Spring and, Fall SDG&E CHP Categories

5.2.4 All of California Results

Simulations are repeated for the entire state of California including all the major utilities and each CHP generation category. The results are presented in Figure 22.

For the summer peak, every CHP category provides a transmission benefit, when all counties and utilities are combined. This indicates the counties which are detrimentally affected are offset by the beneficially affected counties. The most beneficial CHP category is the 0 to 5 MW category, 452 MW is installed resulting in a RTBR of -1.0 in Summer, a small positive of 0.07 in Spring and a negative RTBR of -0.03 in Fall. In the fall, there is little transmission benefit to adding CHP, the result is either a very small or neutral RTBR moving towards a positive RTBR for the larger MW categories.

The 5 to 20 MW category is beneficial to the grid in Summer and Spring, with 484 MW in Summer and 632 MW in Spring, both give negative RTBRs. In summer, the resultant RTBR for the 5 to 20 MW category is -0.07, and in Spring it is -0.4. In Fall 632 MW in the 5 to 20 MW category is dispatched as in Spring, but it results in a detrimental RTBR of 0.14. The combination of the 0 to 5 MW category and 5 to 20 MW category is beneficial again in Summer and Spring, with negative RTBR's of -0.5, and -0.2 respectively.

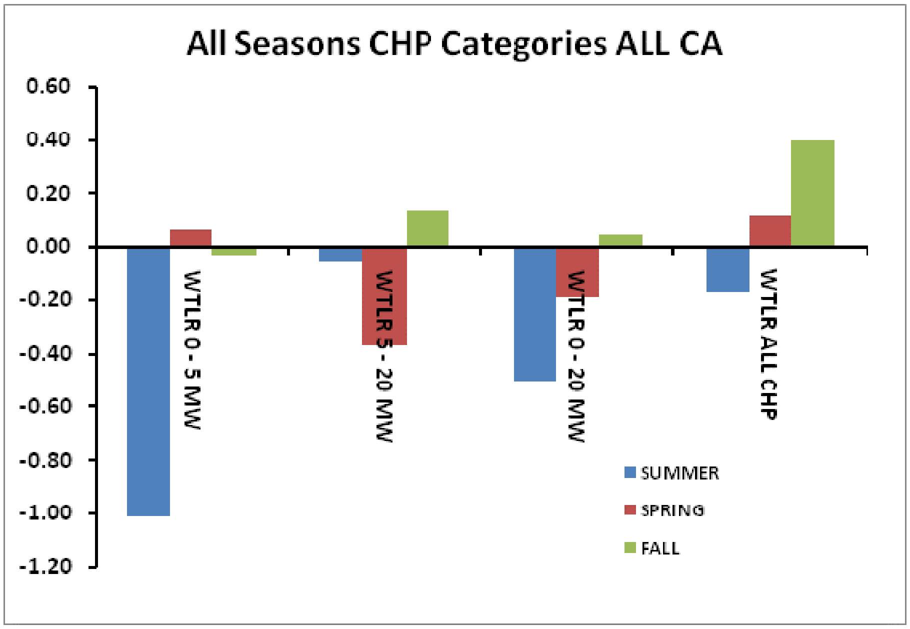


Figure 28: Summer, Spring and Fall analysis for all CHP categories

As in the 5 to 20 MW category, the RTBR in Fall is positive and results in a RTBR of 0.05. When all available CHP is dispatched in Summer (0 to greater than 20 MW) the result is beneficial in Summer.

In Spring, dispatching 4,119 MW (the maximum amount possible without additional transmission overloads), results in a detrimental effect shown by a positive RTBR of 0.1. It was possible to dispatch 5,030 MW of CHP in Fall, without additional steady state overloaded lines but the resultant RTBR is positive at approximately 0.4.

The overall RTBR results for each season and CHP category are shown in Table 31for each of the utilities and the entire state of California. The red areas indicate negative RTBRs, where inserting more CHP generation provides transmission benefits. The blue areas indicate positive RTBRs where inserting more CHP generation is detrimental and the yellow areas are neutral, where there is no effect, or no generation dispatched.

Table 31: All of 2020 California results, split by season and size of installed generation

Utility	Cat.	CHP MW Summer	RTBR Summer	RTBR Spring	RTBR Fall
PGE	0 to 5 MW	197	-1.18	-0.17	0.15
	5 to 20 MW	309	-0.78	-0.67	0.65
	0 to 20 MW	506	-0.98	-0.50	0.36
	ALL CHP MW	1473	-0.26	0.14	1.72
LADWP	0 to 5 MW	38	-0.27	0.00	-0.04
	5 to 20 MW	0	0.00	0.00	0.00
	0 to 20 MW	38	-0.27	0.00	-0.02
	ALL CHP MW	1705	0.63	0.00	0.01
IID	0 to 5 MW	0	0.00	0.00	0.00
	5 to 20 MW	0	0.00	0.00	0.00
	0 to 20 MW	0	0.00	0.00	0.00
	ALL CHP MW	106	-0.02	0.00	0.50
SDGE	0 to 5 MW	17	-0.44	0.00	0.00
	5 to 20 MW	14	-0.73	0.00	0.00
	0 to 20 MW	31	-0.51	0.00	0.00
	ALL CHP MW	31	0.00	0.00	0.00
SCE	0 to 5 MW	196	-0.69	-0.17	-0.04
	5 to 20 MW	172	1.69	-0.67	0.00
	0 to 20 MW	368	0.45	-0.50	-0.02
	ALL CHP MW	2207	0.03	0.14	0.01
ALL CA	0 to 5 MW	452	-1.01	0.07	-0.03
	5 to 20 MW	484	-0.06	-0.37	0.14
	0 to 20 MW	936	-0.50	-0.19	0.05
	ALL CHP MW	4015	-0.17	0.12	0.40

6 ANALYSIS OF EMISSIONS REDUCTION WITH CHP

CHP generators can reduce CO_2, NOx and fuel usage in California. In addition to the CHP resources, the base case includes almost 3,000 MW of residential PV as required under the California Solar Initiative. The impact of PV on the emissions is included following the CHP analysis. This section is divided into subsections:

- Determine possible CHP locations and Potential CHP MW at each location
- Potential MW at each site based on the current steam load
- Development and explanation of the equations
- Sample Calculation
- Final Results

6.1 Derivation of CHP Potential MW

The CHP locations for this analysis are determined using the MIPD (Major Industrial Plant Database) provided by EEA/ICF. This database provides information on the current electricity and steam demand of the existing and potential CHP plants. The potential mega-watt and heat generation for CHP at these locations is derived by EEA/ICF as a factor of the heat value per pound of the steam (assumed as 1,200 Btu/lb [2]) and the amount of heat the unit is required to produce, in pounds. The power to heat ratio is based on the size of the current steam load and is used in EEA/ICF's calculations to determine the number of MW which could be produced at each steam load location, the range is detailed in Table 32.

Table 32: Range for power to heat ratios

Steam Range (lb's)	Power/Heat ratio
0k to 70k	0.27
70k to 100k	0.35
100k to 180k	0.39
180k and above	0.68

CHP generators are either Combined Cycle (CC) or Gas Turbine (GT). A combined cycle CHP is commonly used in larger CHP sites while a gas turbine is used in smaller CHP sites. For this analysis, the CHP units with a potential generating capacity below 100 MW are denoted as GT.

The projected installed MW is the potential MW derivation (from the MIPD described above) minus the existing CHP capacity (also from the MIPD described above). The grid export potential is the CHP potential minus the existing electrical demand. The calculation for total emissions is based on the dispatched MW of the full potential MW.

6.2 Calculation of Emissions and Fuel Savings

In order to calculate the fuel usage and savings with the installation of CHP, plant efficiencies are selected. The efficiencies and emission rates are based on California Energy Commission (CEC) guidelines [3]. The guidelines in Table 33 are for the overall efficiency of grid electricity, boiler operation and the average CHP (combined thermal and electric efficiency). The guidelines also state values of CO_2 emission per MMBtu of fuel used in each of these categories, and NOx per MMBTu of fuel used.

Table 33: Assumptions for the analysis [3]

Assumption Category	Efficiency	CO2 Emissions (lb/MMBTu)	NOx Emissions (lb/MMBTu)
Grid Electricity	46 %	117	0.02
Boiler Heat	80 %	117	0.02
CHP Electricity and Heat	75 %	117	0.02

The assumed efficiency (Table 33 column 2) is used to calculate the fuel required for electricity and hear generation, where η is efficiency, W_E is Electricity Produced (Btu), Q_{TH}, Thermal Energy Produced (Btu), Q_{FUEL} , Fuel flow-rate (Btu/hr). The unknown in the equation below is the fuel flow rate. The other three variables are either assumed or given in the CHP data. CO_2 and NOx emissions are then calculated from the fuel flow rate or usage, and the difference between the existing and new system is the savings [1].

$$\eta = \frac{W_E + Q_{TH}}{Q_{FUEL}}$$

The following operational and installation conditions are assumed in the analysis:

- Electrical and thermal energy required by the industrial site is met by the new CHP units, replacing grid electricity and heat from a boiler
- Electrical energy not met by the new CHP is imported from the grid
- New CHP units often generate more electricity than required by the Industrial Plant therefore this excess electrical energy from CHP is exported to the grid

- Electricity generated by the dispatched CHP (dispatched is occasionally less than potential) less than load, deficit required comes from grid electricity.

6.3 Sample Calculation

In the sample calculation below, the dispatched CHP does not meet the full load of the industrial site but the full steam load is met. The steam load in this example is 109,405 lb/hr, and the heat to power ratio is 0.39 as shown in Table 33 above. Using a heat content of 1,200 Btu/lb, the equivalent generating capacity of the steam load is 35 MW shown in the equation below. From the given CHP data, the current electrical load at this site is 70 MW therefore the remaining MW potential for CHP is 35 MW, leaving 35 MW to be imported from the grid, and to be accounted for as grid electricity in the following analysis.

Equivalent steam generating capacity = (steam load in lbs * the heat to power ratio) / heat content

(109,405 * 0.39)/1,200 = 35 MW

Total load – steam load = import or export from CHP

70 – 35 = 35 MW import from grid

The boiler generates 109,405 lb of heat. With an assumed efficiency of 80 %, or 0.8 (Table 33), the fuel usage is calculated as follows,

$$0.8 = \left(\frac{(109405 lb * 0.0012(\frac{MMBtu}{lb}/hr))}{Q_{FUEL}} \right)$$

The 1,200 BTU/lb is converted to 0.0012 MMBTU/lb

Qfuel = (109,405*.0012)/0.8 = 164 MMBTu/hr

The fuel rate is therefore 164 MMBTu/hr. Using the rates for CO2 and NOx emissions for the boiler in Table 33, the boiler emissions are calculated as shown below.

$$CO2 = 164 \frac{MMBtu}{hr} * 117 \frac{lb}{MMBtu}$$

$$NOx = 164 \frac{MMBtu}{hr} * 0.02 \frac{lb}{MMBtu}$$

The emission rates are therefore 19,201lb-CO2/hr, and 3.3 lb-NOx/hr.

In the no CHP case, 70 MW of grid electricity is used, at 46 % efficiency (Table 33) the fuel rate and emissions are calculated from this also as follows, 3.412 is the constant used to convert MW to MMBtu/hr, required to keep units consistent.

$$0.46 = \frac{70\ MW * (3.412MMBTu/hr)/MW}{Q_{FUEL}}$$

The fuel rate for grid electricity is therefore 519 MMBTu/hr. Using the rates for CO2 and NOx for the grid in Table 33, multiplied by the effective fuel rate calculated above (CO2 = 117 lb/MMBTu, NOx = 0.02 lb/MMBTu), the grid emissions are calculated.

$$CO_2 = 519\frac{MMBtu}{hr} * 117\frac{lb}{MMBtu}$$

$$NOx = 519\frac{MMBtu}{hr} * 0.02\frac{lb}{MMBtu}$$

The emission rates are therefore 60,723 lbCO2/hr, and 10.4 lbNOx/hr for the 70 MW of grid electricity required initially before any CHP is installed.

For the new CHP, the fuel rate is calculated as a combined heat and power calculation from assumed efficiency using the equation above and the assumed efficiency and steam rate for CHP, converted into the correct units again. The fuel rate is calculated from the current steam load at this site that 35 MW of CHP was potentially available.

$$0.75 = \frac{(35\ MW * (3.412MMBTu/hr)/MW) + (131MMBTu/hr)}{Q_{FUEL}}$$

The calculated fuel rate for the CHP is therefore 334 MMBtu/hr for the new CHP, the CO2 and NOx emissions are calculated as above resulting in 39,078 lb-CO2/hr and 6.7 lb-NOx/hr for the CHP only. The CHP dispatch does not provide enough supplemental energy therefore 35 MW (of 70 MW electricity required in total at this site) is provided by the grid and accounted for in the emissions and fuel calculations, and added to the total fuel rate, and emissions for the new CHP. The final results of the sample calculation are provided in Table 34.

Table 34: Results of Sample Calculation

	Fuel Required (MMBTu/hr)	CO2 Emissions (lbCO2/hr)	NOx (lbNOx/hr)
Original System	683	79853	10.1
New System	594	69440	11.9
SAVINGS	89	10413	1.8

6.4 All CHP units combined results

For all the CHP units dispatched in 2020 Summer and following the process detailed in sample calculation for each unit (split for 0 to 5 MW, 5 to 20 MW and >20 MW) the hourly results are tabulated (Table 35).

Table 35: Annual savings with replacement of steam and electricity load with CHP

CHP Size	MW of Units Dispatched	Fuel Saved (MMBTu/Yr), 90% Capacity Factor	CO_2 reduction (TonCO2/yr), 90% Capacity Factor	NOx Reduction (lbNOx/yr), 90% capacity Factor
0 to 5 MW	371	15,596,843	912,415	311,937
5 to 20 MW	486	12,090,672	1,703,742	582,476
>20 MW	4,173	84,558,130	5,517,609	1,886,362
TOTAL	**5,030**	**112,245,645**	**8,133,766**	**2,780,775**

Assuming a 90% capacity factor for the year, the yearly savings can be calculated (Table 36).

Table 36: Yearly savings with replacement of steam and electricity load with CHP

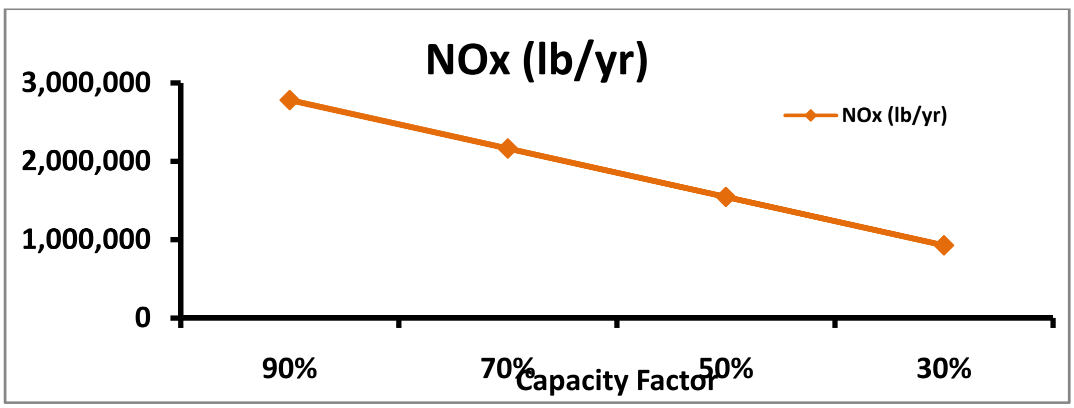
MW of Units Dispatched	Fuel Saved (MMBTu/YEAR), 90% Capacity Factor	CO2 reduction (TonCO2/YEAR), 90% Capacity Factor	Nox Reduction (lbNOx/YEAR), 90% Capacity Factor
5,030	112,245,645	8,133,766	2,780,775

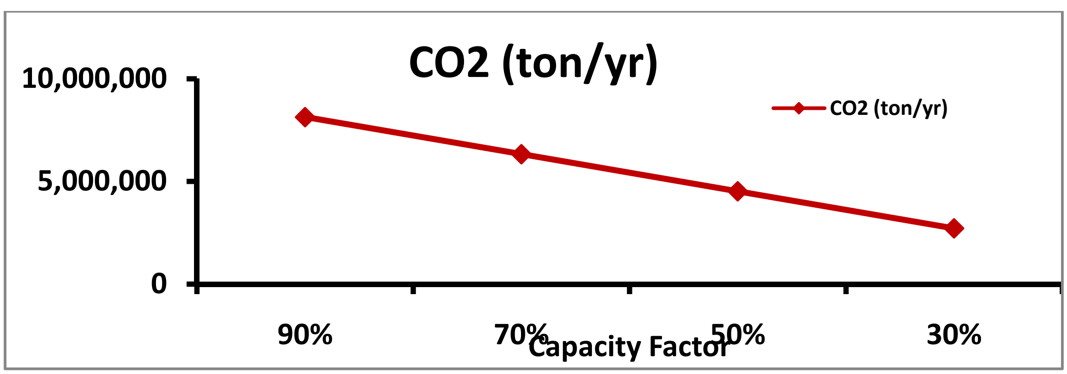
The maximum CHP capacity dispatched is 5,030 MW. Separating this by utility area shows the specific impact for each utility (Table 37).

Table 37: Yearly savings with CHP separated by Utility in California

Utility	MW of Units Dispatched	Fuel Saved (MMBTu/YEAR), 90% Capacity Factor	CO2 reduction (TonCO2/YEAR), 90% Capacity Factor	Nox Reduction (lbNOx/YEAR), 90% Capacity Factor
PG&E	1,521	33,845,019	2,855,477	976,231
SCE	1,659	56,855,559	4,017,903	1,373,642
LADWP	1,705	14,882,078	870,602	297,642
IID & SDG&E	145	6,662,989	389,785	133,260

In Table 37, a CHP capacity factor of 90% is used. Figure 23 below shows the impact of changing CHP capacity factor on fuel savings, SO2 and NOx. The capcity factor decreases linearly and therefore the total emissions savings decrease linealry as the capacity factor changes from 90% to 30%.





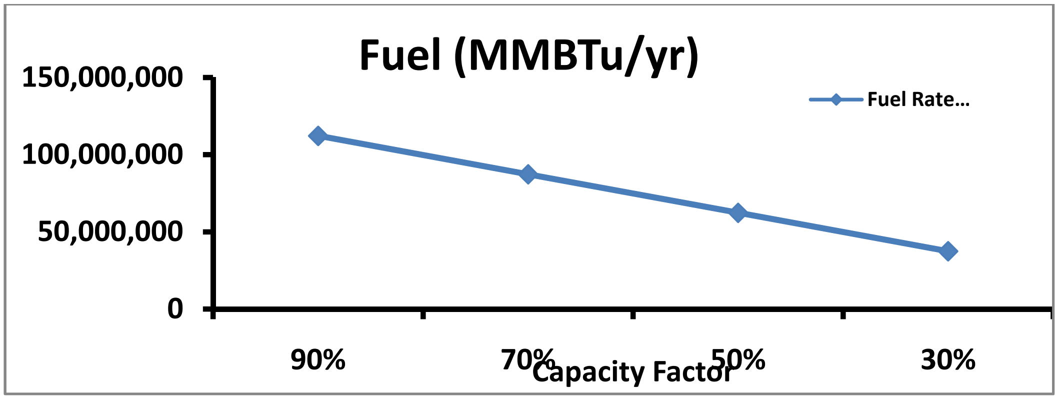


Figure 29: Range of Capacity factors for CHP dispatch and Emissions analysis

6.5 PV Contribution to Emissions and Fuel Usage Reductions

The second part of the analysis projects fuel and emission savings from the dispatch of PV resources in the base case. In the base case, the million new homes with PV resources are modeled. These new PV resources are equivalent to 2,895 MW installed or 1,653 MW at the time of the 2020 summer system peak. The PV calculation is simpler than for CHP since a PV resource is a direct replacement of natural gas generation. For this example, the same emission, fuel rates and grid efficiency of 46% are used in the calculation. The results are presented in Table 38. Since PV resources are emission free, the full gas and emission reductions can be allocated to the PV resources. The local energy consumption of PV energy is assumed to result in a turn-down in natural gas generation. The calculation is therefore the savings from natural gas generation.

Table 38: Hourly savings with replacement of grid electricity load with PV

MW of Units Installed	Fuel Saved (MMBTu/hr)	CO2 reduction (TonCO2/hr)	NOx Reduction (lbNOx/hr)
2895	21,398	1,252	1,498

A capacity factor of 17% is assumed for the PV to calculate the yearly savings as shown in Table 39.

Table 39: Yearly savings with replacement of grid electricity load with PV

MW of Units Installed	Fuel Saved (MMBTu/Yr)	CO2 reduction (TonCO2/Yr)	NOx Reduction (lbNOx/Yr)
2895	31,864,643	1,864,140	2,230,595

In conclusion, the proposed CHP and PV installations result in significant savings of fuel, and therefore CO_2 and NOx emission reduction. This results in significant economic savings for the industrial and commercial businesses and assists in meeting environmental requirements. The calculations used are based on work published by CEC.

7 REFERENCES

[1] http://www.census.gov/geo/www/ua/ua_2k.html

[2] "Industrial Sector Combined Heat and Power Export Market Potential", May 2009, CEC-500-2009-010

[3] Personal Communication, Arthur J. Soinski, California Energy Commission, April 29th 2009

Appendix I: Maps of utility areas and locations of generation

Figure 24 shows the locations of the 2010 existing CHP locations. The locations are divided into two groups. The first group is the 1 MW to 100 MW CHP resources while the second figure is the 100 MW to 500 MW CHP resources.

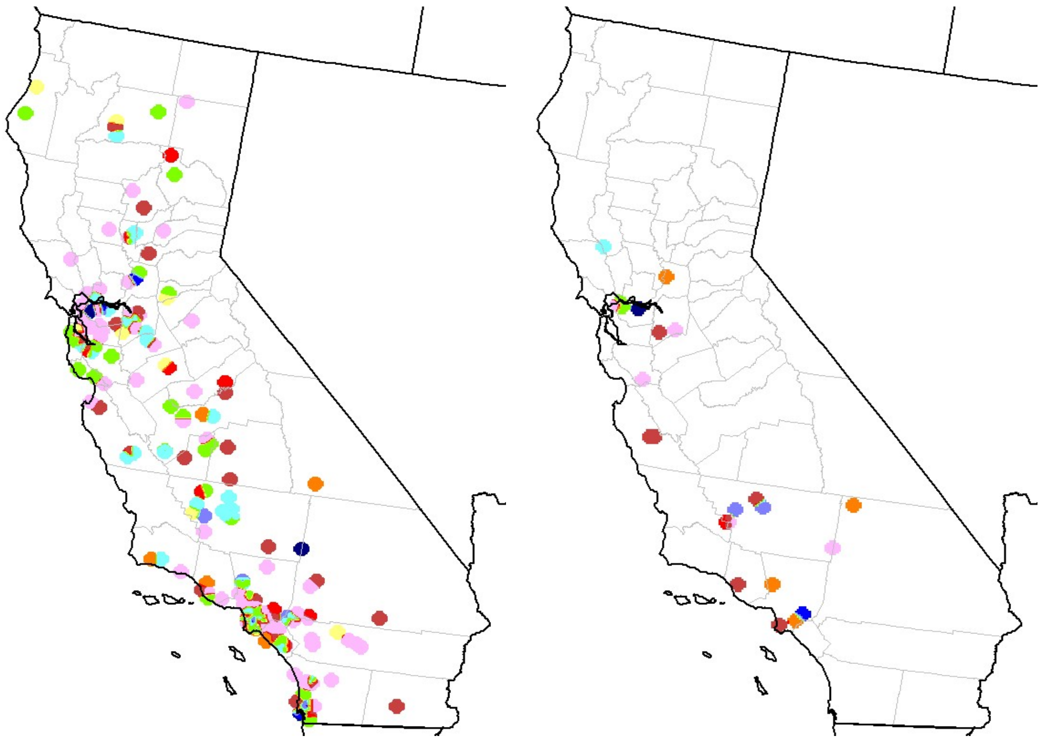


Figure 30: Existing CHP Locations for the 1 MW to 100 MW and the 100 MW to 500 MW

The concentrations and number of CHP and PV in each utility area is plotted on the geographical maps below. Zip code boundaries are also included. In general the zip codes contain at most 3 CHP units, but most commonly only one. The largest concentration of units is in the PG&E area in Figure 25, SCE in Figure 26, SDG&E is Figure 27, LADWP in Figure 28. Figure 29 shows the PV concentrations.

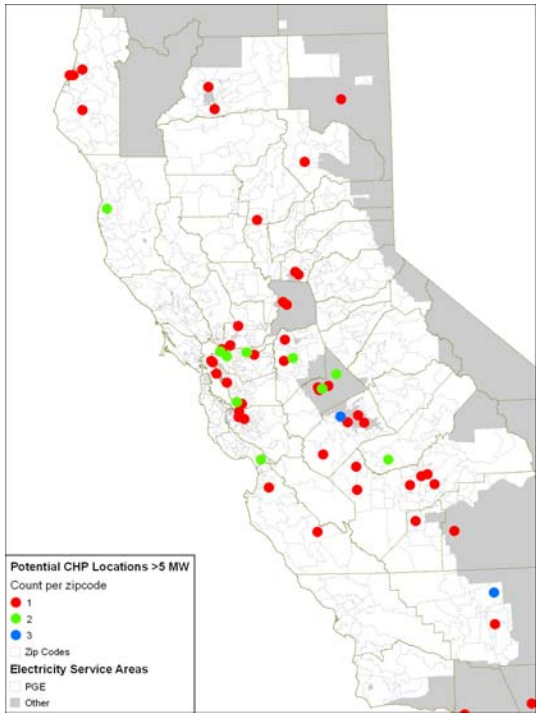


Figure 31: PG&E CHP Units and concentration, by zip-code

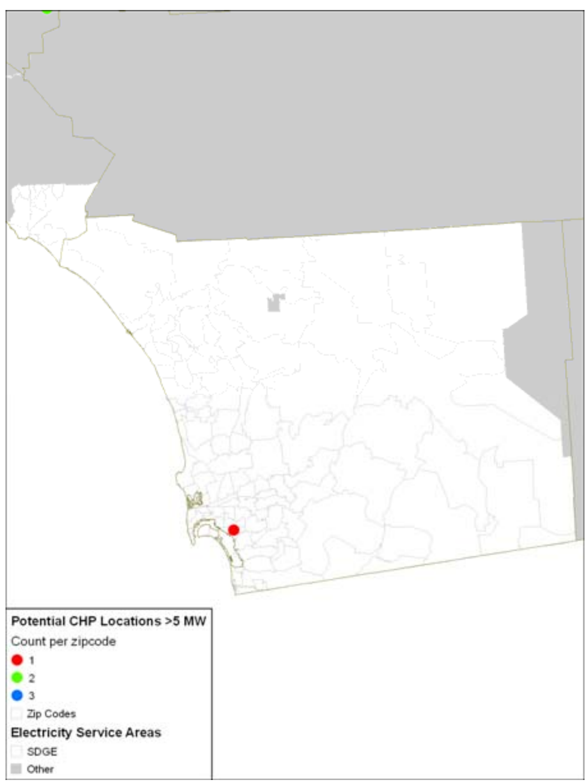


Figure 32: SDG&E CHP Units and concentration, by zip-code

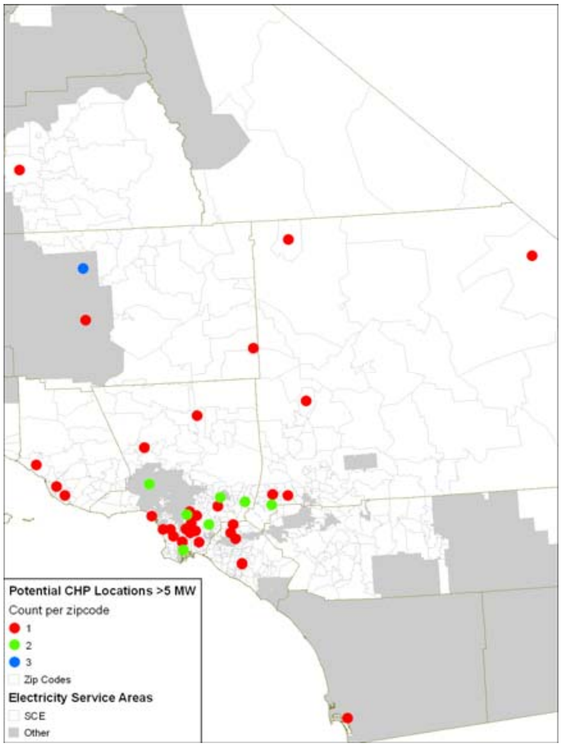


Figure 33: SCE CHP Units and concentration, by zip-code

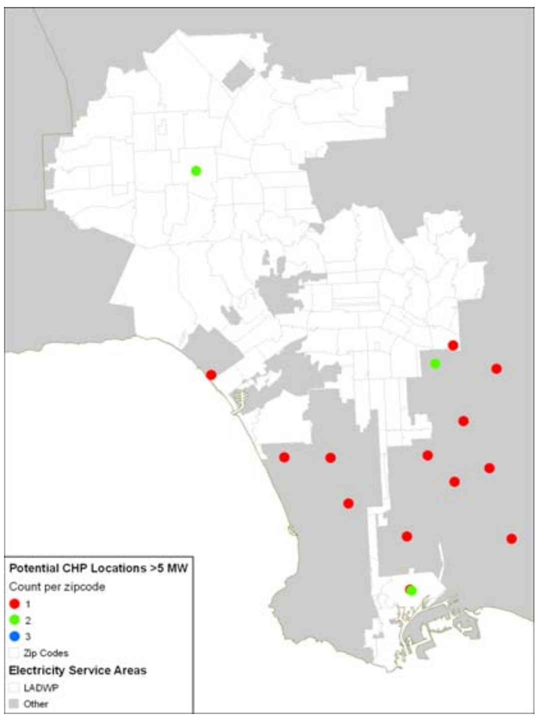


Figure 34: LADWP CHP Units and concentration, by zip-code

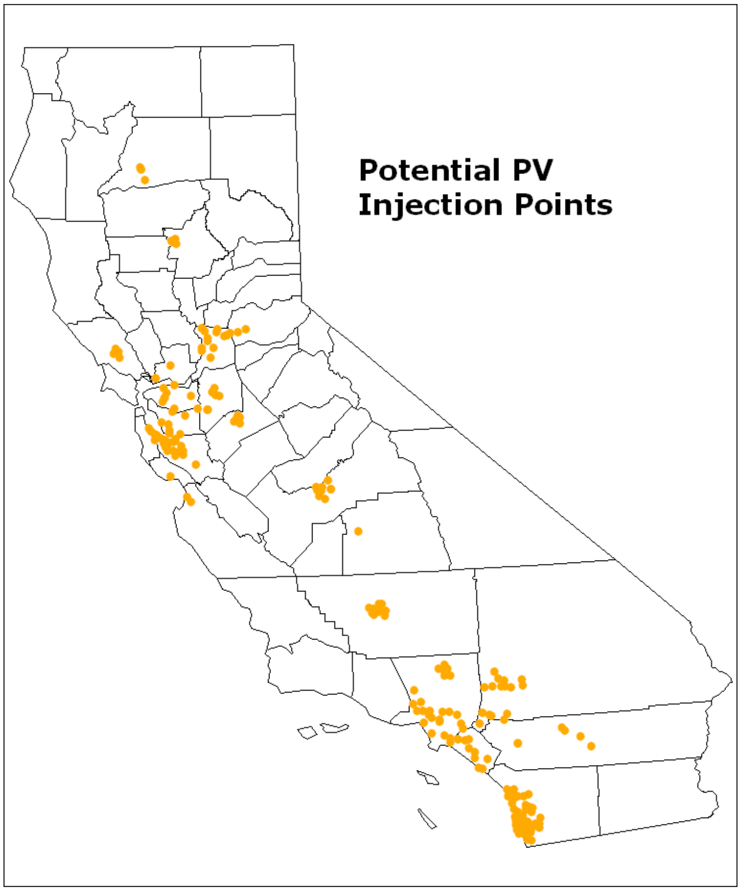


Figure 35: ALL CA PV Units and concentration

Appendix II: Maximum and dispatched generation

For each of the cases, Summer, Spring and Fall and for each of the utilities, and size category of CHP and PV, the maximum generation proposed and the maximum installed is detailed in Table 40, Table 41, and Table 42.

Table 40: Summer MW CHP potential and dispatched, by utility

Location	Maximum Generation (MW)			Dispatched Generation (MW)		
	0 to 5 MW	5 to 20 MW CHP	+ 20 MW CHP	0 to 5 MW	5 to 20 MW CHP	+ 20 MW CHP
PGE	197	410	3504	197	410	1476
IID	0	0	114	0	0	114
LADWP	38	6	1792	38	6	1053
SCE	196	202	1261	196	202	1121
SDG&E	17	14	0	17	14	0
ALL CA	452	632	6671	452	632	3833

Table 41: Spring MW CHP potential and dispatched, by utility

Location	Maximum Generation (MW)			Dispatched Generation (MW)		
	0 to 5 MW	5 to 20 MW CHP	+ 20 MW CHP	0 to 5 MW	5 to 20 MW CHP	+ 20 MW CHP
PGE	197	410	3,504	197	410	1,290
IID	0	0	114	0	0	114
LADWP	38	0	1,792	38	0	1,079
SCE	196	202	1,261	196	202	1,150
SDG&E	17	14	0	17	14	0
ALL CA	452	615	6,671	452	615	2,644

Table 42: Fall MW CHP potential and dispatched, by utility

Location	Maximum Generation (MW)			Dispatched Generation (MW)		
	0 to 5 MW	5 to 20 MW CHP	+ 20 MW CHP	0 to 5 MW	5 to 20 MW CHP	+ 20 MW CHP
PGE	197	410	3504	197	410	1,354

IID	0	0	114	0	0	70
LADWP	38	6	1,792	38	6	943
SCE	196	202	1,261	196	202	1,125
SDG&E	17	14	0	17	14	0
ALL CA	452	626	6,671	452	626	3,523

Appendix III: CHP Organized by type of industry, utility and CHP size category

Table 43: Potential MW, split by type of industry, CHP size category and Utility

CHP CATEGORY	UTILITY	INDUSTRY TYPE	MW POTENTIAL
0 TO 5 MW			
	LADWP	CHEMICALS	3.12
		ELECTRONIC	3.51
		FABRICATED METAL PRODUCTS	6.18
		FOOD	9.06
		PETROLEUM	4.29
		PRINTING	2.44
		TEXTILES	2.97
	IID	CHEMICALS	0.88
		ELECTRONIC	4.17
		FABRICATED METAL PRODUCTS	1.91
		INSTRUMENTS	0.85
		MISC. MANUFACTURE	0.68
		PAPER	1.61
		PRIMARY METAL IND	1.08
		TRANSPORTATION	0.96
	PG&E	CHEMICALS	24.34
		ELECTRONIC	1.98
		FABRICATED METAL PRODUCTS	5.59
		FOOD	81.03
		INDUSTRIAL MACHINERY	0.78
		INSTRUMENTS	1.11
		LEATHER	1.46
		LUMBER	21.71
		PAPER	26.13
		PETROLEUM	4.40
		PRIMARY METAL IND	5.40
		PRINTING	0.89
		RUBBER	8.21
		STONE & GLASS	4.49
		TEXTILE	2.08
		TRANSPORTATION	2.26
	SCE	APPAREL	0.60
		CHEMICALS	8.67
		ELECTRONIC	7.12
		FABRICATED METAL PRODUCTS	9.36

		FOOD	44.86
	SCE	FURNITURE	1.20
		INDUSTRIAL MACHINERY	2.17
		INSTRUMENTS	2.03
		PAPER	28.67
		PETROLEUM	4.90
		PRIMARY METAL IND	2.81
		RUBBER	9.87
		STONE & GLASS	5.16
		TEXTILE	2.40
		TRANSPORTATION	7.45
	SDG&E	CHEMICALS	1.09
		ELECTRONIC	3.21
		FABRICATED METAL PRODUCTS	0.87
		FOOD	0.94
		INDUSTRIAL MACHINERY	1.34
		INSTRUMENTS	2.64
		RUBBER	1.68
		TRANSPORTATION	0.73
5 TO 20 MW			
	IID	FOOD	6.95
	PG&E	CHEMICALS	12.66
		FOOD	151.39
		FURNITURE	4.67
		LUMBER	34.70
		PAPER	33.57
		PRINTING	12.10
		RUBBER	6.41
		STONE & GLASS	4.72
		TRANSPORTATION	23.23
	SCE	CHEMICALS	37.72
		FABRICATED METAL PRODUCTS	6.34
		FOOD	16.55
		FURNITURE	4.53
		INSTRUMENTS	10.40
		PAPER	62.69
		PETROLEUM	36.04
		PRIMARY METAL IND	21.52
		RUBBER	11.56
		STONE & GLASS	4.60
		TEXTILE	19.49
		TRANSPORTATION	6.15
		PAPER	5.71
>20 MW			
	LADWP	PETROLEUM	723.82

		FOOD	45.88
		TRANSPORTATION	25.62
	IID	FOOD	106.14
	PG&E	PETROLEUM	1931.80
		PAPER	274.47
		LUMBER	354.12
		PRIMARY METAL IND.	35.44
	SCE	CHEMICALS	154.56
		FOOD	140.50
		PAPER	33.83
		PETROLEUM	767.46
		TRANSPORTATION	126.26